ADVANCED COMMUNICATIONS TECHNOLOGY

Technology Assessment of Mobile Satellite System Alternatives

Prepared for:

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Executive Summary

Like many other organizations in this digital age, the Coast Guard's communications requirements have been increasing every year. The Coast Guard has changed its operating doctrine, relying more on joint task force/multi-unit operating concepts. Information support to deployed forces is also becoming more centralized, as evidenced by LEIS II, STARS, and other information management systems. Further, there is a general trend to exchange greater amounts of information both to support the decision-making process by the on-scene commander and to enable the shore-based commander to monitor operations and make strategic decisions. It is predicted that mobile communications requirements will surpass the capacity of existing HF, DoD military satellite (MILSATCOM), and Inmarsat systems by the year 2000.

Due to the finite bandwidth of HF and MILSATCOM systems and the austere budgetary climate the Coast Guard must operate in, it appears likely that the Coast Guard will shift from owned to contracted communications services. The R&D Center's report, *Technology Assessment of USCG Long Range Communications Alternatives* dated March 1995, predicts that commercial mobile satellite communications services will be significantly more economical than Coast Guard owned and operated HF communications stations to meet Command and Control (C^2) communications requirements, when all direct and indirect costs are considered. In addition, commercial satellite systems appear to be the only solution which will meet expanding Coast Guard bandwidth requirements. However, as also noted in the above report, some HF capability will need to be retained to meet Public Safety requirements and to provide back-up communications services for Coast Guard operations. Not all Coast Guard communications requirements will be economically or technically possible to be met by commercial satellite systems.

This report describes the results of extensive research into the commercial mobile satellite (MSAT) communications market. All current and emerging MSAT communications systems are identified and described in the sections below. We have chosen to categorize the systems based upon when they will be available: Now, Soon (1998–1999), Turn-of-the-Century (2000–2001), and On-the-Horizon (2002+). Within each year-group, all types of systems (data-only, voice/data, and broadband) are considered. The most promising mobile satellite systems (the ones that appear to meet the documented requirements) will be tested at the R&D Center to establish an independent, impartial evaluation of each system. A preliminary test outline and list of systems to be evaluated is included in this report. At the completion of each system test, results will be reported separately. Due to the rapid developments in this field, a second MSAT Evaluation report will be completed in the first quarter of FY99 as an update to this work.

Currently there are only five satellite systems with a total of 10 satellites in operation (counting only those systems that support communications to mobile users). Over the next ten years, another 41 systems and 1,033 satellites are planned for launch into GEO, MEO, and LEO orbits (counting all proposed systems). While not all of these systems will actually be launched and successful, there will still be an incredible number of options to choose from. Unfortunately, for many of these proposed systems, it is not known to what extent they will support mobile terminals. The industry will need to be tracked over the next several years, as some systems are launched and plans are solidified on others. The Mobile Communications Infrastructure project will do just that. As plans of many of these systems are solidified, this Satellite Alternatives technology assessment will be revisited and updated. As systems are launched, those that appear to meet Coast Guard communications requirements will be tested, both in the lab and in the field. Finally, as data becomes available, cost benefit analyses comparing the different systems will be done in order to identify which systems the Coast Guard should procure.

It is doubtful that a one-size-fits-all type solution exists. Due to the wide variance in Coast Guard Missions and platforms, it is more likely that different systems will be best for different platforms. There are three categories of service: data-only, voice/data, and broadband data. Currently, shipboard systems are only available in the first two categories. A shipboard terminal for two-way broadband data will probably not be available until the Ka-band systems are operational in 2002.

1. Introduction / Background

Satellite communications were first proposed in 1945 by author Arthur C. Clark in an article entitled "Extraterrestrial Relays" written for the British magazine *Wireless World*. The first satellite wasn't launched until a decade later when the Soviet Union stunned the world with Sputnik I in 1957. The United States quickly followed with the launch of Explorer I four months later, and the formation of NASA in July 1958. The first, albeit experimental, communications satellite was the US Army's SCORE (Signal Communications by Orbiting Relay Equipment) launched in December 1958. This was the first of series of experimental satellites leading to the first operational, geostationary communications satellites, Syncom II and Syncom III which were placed in orbit in 1963 and 1964. They used an uplink frequency of 7.36 GHz, a downlink at 1.825 GHz and operated until 1966, including providing live TV transmission of the 1964 Tokyo Olympics.

It was another 15 years before the first commercial mobile satellite service appeared. Inmarsat was formed in 1979 to provide communications to the maritime community. However, the initial mobile equipment was characterized by large size and weight, a limited set of services, high equipment cost, and expensive usage charges. As a result, alternative means of communications, such as high frequency (HF) radio and the U.S. Navy Fleet Satellite Communications continued to be the Coast Guard's primary means of long range communications.

In the 30 years following Sputnik there were relatively few systems that could support mobile users—Inmarsat being the primary option. Starting in the 1980's, new advances in technology such as digital modulation and advanced signal processing started to lead towards higher powered transponders, advanced switching, and multiple spot beams. These improvements allow for more capacity, more bandwidth, and smaller terminals—all important for mobile users. Also, the number of options is going to increase greatly in the near future. Over the next ten years, hundreds of new satellites will be launched into orbit, multiplying the options for mobile communications.

Like many other organizations in this digital age, the Coast Guard's communications requirements[1] have been increasing every year. It is predicted that mobile communications requirements will surpass the capacity of existing HF, DoD military satellite (MILSATCOM), and Inmarsat systems by the year 2000. The Coast Guard has changed its operating doctrine, relying more on joint task force/multi-unit operating concepts. Information support to deployed forces is becoming more centralized, as evidenced by LEIS II, STARS, and other information management systems. Further, there is a general trend to exchange greater amounts of information both to support the decision-making process by the on-scene commander and to enable the shore-based commander to monitor operations and make strategic decisions.

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[1] Current communications requirements are captured in the "USCG C4I Baseline Architecture" and the R&D Center "Mobile Communications Requirements Report."

considered. In addition, commercial satellite systems appear to be the only solution which will meet expanding Coast Guard bandwidth requirements. However, as also noted in the above report, some HF capability will need to be retained to meet Public Safety requirements and to provide back-up communications services for Coast Guard operations. Not all Coast Guard communications requirements will be economically or technically possible to be met by commercial satellite systems.

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2. Technology Primer

This section explains some of the basics of the language of satellite systems. The different satellite orbits, common frequency bands, systems segments, and multiplexing techniques are all explained. People new to satellite communications are encouraged to read this tutorial.

2.1 System Segments

2.1.1 Ground segment

The ground segment consists of the equipment located on the ground that controls and monitors the satellites and links them into terrestrial communications networks. An earth station[2] includes everything that is involved in communicating with satellites. There may be few or many, depending on the areas of coverage. There may be only one transmit/receive antenna for an earth station, or a group of antennas working together to access several satellite systems, known as a Teleport. An earth station is a self-contained hub of people and hardware working together for the success of an overall communications system. This involves the monitoring of transmitted and received signals as well as system maintenance.

2.1.2 Space segment

The space segment[3] is little more than the satellite or group of satellites in one or more of the orbital configurations outlined in 2-1. There could also be one or more spare satellites which could fill the gap in the constellation should one go bad. The satellites function as high altitude transponders, making it possible to relay information over a wide area. The methods of signal transmission, reception, hand off to other satellites, and so on often vary from one type of system to another, but the hardware involved in the performance of those functions is usually very similar.

The satellites are equipped to receive information from an earth station via an uplink frequency different from the downlink frequency used to pass on the information back to an earth receiver. The proper uplink and downlink frequencies are decided upon for the type of service, then authorized by national or international telecommunications laws and treaties.

The satellites are also constantly tracked and communications are maintained by telemetry, to ensure they are operational and still in the proper orbit. The overall health of the satellites is continuously monitored and evaluated.

2.1.3 User segment

The user segment is made up of the equipment used by the subscribers or users of the satellite system. Generally, the satellite communications industry is aimed at users in remote regions who do not have adequate local access such as developing countries. Other prime candidates for

[2] Dr. Joseph N. Pelton, "The 'How To' of Satellite Communications," 2nd Edition; Design Publishers 1995, pp. 13-15.

[3] Dr. Joseph N. Pelton, "The 'How To' of Satellite Communications," 2nd Edition; Design Publishers 1995, pp. 12-13.

satellite services are international business travelers, since good global communications may be the key to their success as a company.[4] A third category of users are those requiring mobile service such as the maritime community.

Satellite communications; however, is more than telephone and television services. It includes high speed data, fax, e-mail (store and forward), and now high speed Internet access. A mobile commuter (national or international) can send and receive information globally, voice or data (e-mail, fax or Internet), via a satellite communications terminal no larger than a laptop computer.[5]

The usage of satellites for cellular telephone service is climbing even in the United States for commuters, public or private. This practice has defined the idea of remoteness in a new way. Users are no longer limited to the length of a telephone cord in order to communicate effectively over global distances for any type of service.

2.2 Satellite Orbits

Satellite communications systems are usually described as being a member of one of three configurations, LEO, MEO, or GEO. Table 2-1 describes characteristics of each configuration.[6] These are illustrated in Figure 2-1, and explained in detail in the subsections below.

Table 2-1 Satellite Orbit Types

Orbital Type	LEO	MEO (ICO)	GEO
Altitude (km)	≈1000—2000 km	10,000-20,000 km	35,786 km
Altitude (miles)	≈620—1245 miles	6,210-12,420 miles	22,237 miles
Orbit	Elliptical/Circular	Circular	Equatorial/Circular
Period	≈1.5—2 hours	≈6 hours	24 hours
Time in View	<20 minutes	a few hours	Stationary
Time Delay	≈6.7 ms	≈66.7 ms	240 ms

[4] "Satellites," NASA Facts on Line, NASA Goddard Space Flight Center; Internet: http://pao.gsfc.nasa.gov/.

[5] John Montgomery, "The Orbiting Internet: Fiber in the Sky," Byte Magazine, November, 1997.

[6] Alex da Silva Curiel Jr., "Orbit Types," pp. 1-3, SSTL, Surrey, UK; Internet http://dspace.dial.pipex.com/plaza/he13/orbtypes.htm.

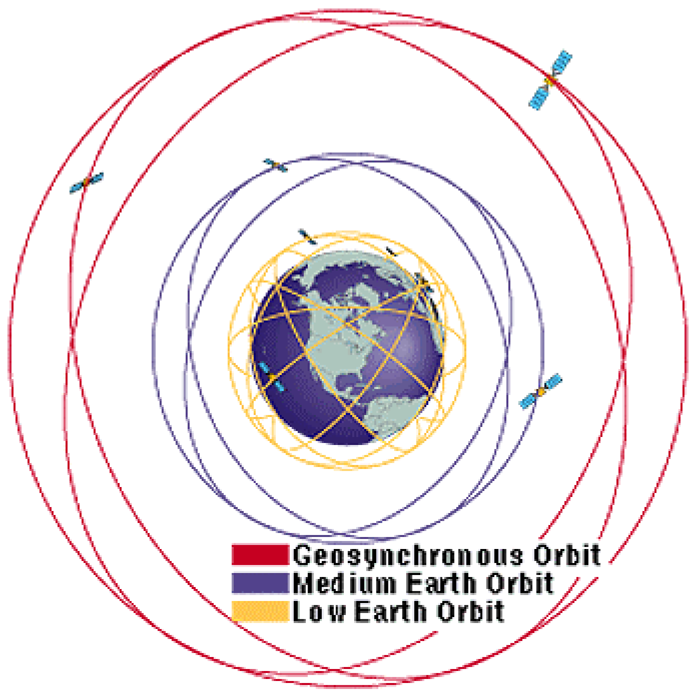

Figure 2-1 LEO/MEO/GEO Orbits[7]

2.2.1 Low Earth Orbit (LEO)

Low Earth Orbit (LEO) satellite constellations occupy orbits very close to the earth, typically less than 1,610 km (1,000 miles). Depending upon altitude, any one satellite will remain above the earth's horizon for only a few minutes. Therefore, the satellite must hand-off the communications link to another satellite just coming into view.

Very often the orbits are circular and circumpolar, with an inclination of about 90° to the equator. As the satellites orbit, the earth literally turns beneath them, offsetting their orbits on every passage. A LEO satellite constellation can provide nearly global communications coverage.[8]

Some communications schemes actually have a mix of satellite planes of both circular and highly elliptical orbits. These are designed to provide greater coverage over high usage land areas with fewer satellites in attendance, but neglect global coverage.

A drawback of LEO systems is that a large number of satellites are required for global coverage, which necessitates an expensive startup cost. Also a LEO satellite orbit will decay in about five years; thus the constellation will essentially be replaced every few years. The greatest payback however, is that there is a very small round-trip propagation time delay from the earth station to

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[7] http://www.globalstar.com/img/tech/leogeo.gif

[8] Alex da Silva Curiel Jr., "Orbit Types," pp. 1-3, SSTL, Surrey, UK; Internet http://dspace.dial.pipex.com/plaza/he13/orbtypes.htm.

the satellite and back. Voice communications will sound more natural. Also the shorter delay increases the feasibility of time latency sensitive data transmission protocols such as TCP/IP.[9]

2.2.2 Medium Earth Orbit (MEO)

Medium Earth Orbit systems (MEO) occupy circular orbits of about 10,000 km (16,100 miles). This orbit is also called an Intermediate Circular Orbit (ICO). Because the orbital period is on the order of 6 hours or more, the satellites remain over the horizon for several hours, making satellite hand-offs less frequent. Therefore, only a few satellites are needed in 2 to 3 orbital planes, to provide global service, making the service less expensive. The satellite orbital decay time is also reduced. Satellites are typically replaced in intervals of 7–15 years.

The tradeoff is a longer propagation delay than in LEO systems. Also, because the signal has to travel further through space, there is also a greater space loss. Degradation of signal and time latency might become an issue in some applications. Many people view MEO orbits as an ideal compromise between the low latency and large number of satellites of LEO systems and the high latency and low number of satellites of GEO systems.

2.2.2.1 Highly Elliptical Orbit (HEO)

A variation on the MEO circular orbit is the Highly Elliptical Orbit (HEO). This is also known as the Molniya orbit after the Soviet Molniya spacecraft which first used this orbit. This is an elliptical orbit above the poles, where the satellite comes close to the Earth on one end (perigee) and far from the Earth on the other end of the orbit (apogee). Due to the physics of orbital dynamics, a satellite will seem to “hang” in the sky at apogee and move very quickly through perigee. A typical HEO stretches from 500–1000 km at perigee over the South Pole to 40,000 km at apogee over the North Pole. This type of orbit provides increased coverage over the Northern Hemisphere and the North Poles. Due to orbital dynamics, the satellite spends most of it’s orbit over the Northern Hemisphere, and is typically seen at a higher elevation angle.

2.2.3 Geostationary Earth Orbit (GEO)

Geostationary Orbit systems (GEO) occupy a circular orbit of 35,786 km or 22,237 miles in an equatorial plane. At this altitude the orbital period exactly matches the orbital period of the Earth. A satellite in this orbital configuration will appear to be fixed in place above the Earth's surface. The service coverage for GEO orbits is from 75° North latitude to 75° South latitude. Near global coverage can be achieved with a minimum of three satellites. However, there is a round-trip transmission delay of about a 480–570 ms, which impacts both voice and data circuits.

The term geosynchronous is often used interchangeably with geostationary. This is however, incorrect. A geosynchronous orbit is any orbit which has a 24-hour period of revolution. It can have any inclination with respect to the equator. A geostationary orbit is the ideal case of a geosynchronous orbit; it is a geosynchronous orbit with 0° inclination. Any inclination other than 0° will make the satellite as viewed from the Earth appear to drift about it’s normal position in the sky.

Sometimes a hybrid of a LEO and a GEO configuration is used to combine the advantages of both; for example, the shorter latency delays for LEO and the larger broadcast area capability of

[9] Allman, Hayes, Kruse, Ostermann, “TCP Performance over Satellite Links,” Ohio University, p. 1; Internet http://jarok.cs.ohiou.edu/papers/.

a GEO. Usually the provider cuts cost by limiting the number of satellites over a specific service area, rather than offer global coverage.

2.3 Frequency Spectrum

Table 2-2 summarizes the major communications frequency bands. The satellite uplink and downlink frequencies listed are only approximations within a wider range of frequencies called bands, represented by letters of the alphabet.[10] Each satellite constellation will have an assigned operational frequency bandwidth within that range. Deviation outside of these assigned frequencies will interfere with other communications assignments.

Generally terrestrial transmissions, such as radio and television, occupy the lower end of the spectrum, while the higher frequencies of the spectrum are more suited to satellite communications. These frequencies are less affected by atmospheric reflection, diffraction and absorption. For example, a rainstorm over a major area will not greatly affect satellite communications, except in the Ka and V bands. However, all communications alternatives remain susceptible to sunspot interference.

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[10] Dr. Joseph N. Pelton, "The 'How To' of Satellite Communications," 2nd Edition; Design Publishers 1995, pp. 16-18, 72-75.

Table 2-2 Satellite Frequency Bands

Band	Frequency[11]
VHF	138–152 MHz
P	0.230–1.00 GHz
UHF	0.430–1.30 GHz
L	1.53–2.7 GHz
S	2.7–3.5 GHz
C	Downlink 3.7–4.2 GHz Uplink 5.925–6.425 GHz
X	Downlink 7.25–7.745 GHz Uplink 7.9–8.395 GHz
Ku (US)	Downlink FSS 11.7–12.2 GHz Downlink DBS 12.2–12.7 GHz Uplink FSS 14–14.5 GHz Uplink DBS 17.3–17.8 GHz
Ka	18–31 GHz
Q	40–47 GHz
V	50–58.2 GHz
W	59–64 GHz

2.4 Regulatory Issues:

In the United States the Federal Communications Commission (FCC) manages and allocates satellite orbital slots for non-Federal organizations that apply for a license to operate a satellite in a particular orbit. Their international counterpart the International Telecommunications Union (ITU) based in Geneva Switzerland.[12]

Ideally the national and international organizations should work together to manage the limited number of available satellite orbital slots. However, this may not be the case. In the United States, being granted a license to operate a satellite in a particular orbit may not guarantee that the organization will be able to use it. The FCC has literally granted licenses to many applicants for the same orbits. The FCC also grants orbit licenses for proposed international use, without

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[11] Hertz (Hz) is the unit of measure for 1 cycle of frequency. One million cycles is equal to 1 Megahertz (MHz) and 1 billion cycles is 1 Gigahertz (GHz).

[12] Dr. Joseph N. Pelton, "The 'How To' of Satellite Communications," 2nd Edition; Design Publishers 1995, pp. pp. 30-31.

requiring the applicant to consult the ITU for international support. This practice is controversial to say the least; however, the problem can only worsen as the number of applicants increases.

Another problem is that the FCC requires that the granted license be used within five years of issuance, while the ITU specifies nine years. If the applicant cannot put their proposed plan into effect within those time boundaries the license is suspended. Since there are more applications for orbit usage than available orbits, it becomes a race as to who can actually launch their satellites and provide the service first.

The ITU has traditionally only recognized and protected spectrum used by geostationary mobile satellite systems, not LEO or MEO systems, although ITU World Radio Conferences are making changes recognizing these systems. Insufficient spectrum exists to support the needs of all these systems.

Neither the FCC nor the ITU provide special regulations or protection regarding safety or emergency (e.g. 911) uses of mobile satellite systems. The FCC in fact denied a USCG petition to require certain minimum emergency calling capability in mobile satellite systems, similar to that of cellular and PCS carriers. Safety uses are recognized however in systems providing maritime and aeronautical mobile satellite systems operating in the L-band spectrum.

2.5 Multiplexing and Multiple Access Techniques

Multiple access techniques are what enable multiple users to use the same finite resources simultaneously. There are four main techniques, FDMA, TDMA, SDMA, and CDMA. In each case, the finite resources are shared among all the users. If the resource allocation is fixed and allocated in advance, the system is called fixed access or pre-assigned access. If the resources are allocated on an as-needed basis in response to user needs and changing traffic conditions, then the system is called demand access or DAMA (demand-assigned multiple access).

Note that Multiple Access is **not** the same as multiplexing, in fact the two are often used together. Multiplexing is the combining of multiple input data streams (or analog channels) into a single larger data stream. This is done prior to the data stream being modulated and sent up to the satellite using one of the multiple access schemes. The two most common methods are Frequency Division Multiplexing (FDM) and Time Division Multiplexing (TDM). Other link access techniques are SCPC, and RMA.

2.5.1 Frequency Division Multiple Access (FDMA)

In Frequency Division Multiple Access the available bandwidth is divided among the users; each user has a different frequency band for transmission. Each user uses their assigned frequency slice of the transponder for the entire time, and all users can transmit simultaneously. The sum of the bandwidth given to each user cannot exceed the total bandwidth to the satellite. Also, the satellite power must be shared across all users. FDMA also requires the use of guard bands between channels to keep signals well separated and therefore has little flexibility.

2.5.2 Time Division Multiple Access (TDMA)

In Time Division Multiple Access each user transmits using the entire available bandwidth, so only one user can transmit at a time. Each user has a different time slot for transmission and uses the entire bandwidth of the transponder for the duration of their time slot. TDMA techniques typically require a common system of timing and control to ensure that two users do not try to transmit during the same time slot. This time slot synchronization increases the system complexity. Also, antenna size can be an issue.

2.5.2.1 Multi-frequency TDMA (MF-TDMA)

This variation on TDMA uses multiple frequencies to increase network bandwidth while reducing transmission power and antenna size. Any terminal may transmit on any one frequency at a given time.

2.5.3 Space Division Multiple Access (SDMA)

Space Division Multiple Access is nothing more than making physically separated paths available for each user. This is typically done by either using separate beams or orthogonal polarizations. Different beams can be implemented as multiple beams from the same satellite or by having multiple satellites, with each satellite covering different geographic regions, or both.

2.5.4 Code Division Multiple Access (CDMA)

In Code Division Multiple Access each user transmits using the entire available bandwidth the entire time. In this case, the signals are separated by orthogonal coding of the signals. This can be done using either frequency-hopping (FH) or direct sequence (DS). In the FH scheme each user transmits with a pseudo-random frequency pattern. In the DS scheme, the baseband signal is modulated with a pseudo-random bit sequence. The power of the satellite is shared among all users.

2.5.5 Demand-Assigned Multiple Access (DAMA)

DAMA allows for the dynamic assignment of bandwidth and satellite power based upon terminal requests (user needs). DAMA is often used in VSAT networks where traffic tends to be bursty; i.e. users need high-speed connectivity for short durations. DAMA can be used with MF-TDMA and SCPC to allocate bandwidth to individual frequencies or dedicated channels. DAMA requires an overhead investment in system control which reduced overall capacity.

2.5.6 Random Multiple Access (RMA)

In this access method, transmissions are made randomly. When messages collide, they are retransmitted after a certain delay. This is similar to the Carrier-Sense Multiple Access (CSMA) used on Ethernet networks. The most common RMA system is the ALOHA system developed by the University of Hawaii. The advantage of random access is low complexity, and no system control overhead. The disadvantage of this random-access scheme is that the maximum utilization is about 18.4%. A simple system called *slotted* ALOHA was developed to improve this using a small amount of network control. By allowing transmissions to occur only at specified times (or within a *slot*), utilization is improved to 38.8%.

2.5.7 Frequency Division Multiplexing (FDM)

In FDM multiple channels of set frequency bands are combined into one larger channel. This is typically used to multiplex analog signals..

2.5.8 Time Division Multiplexing (TDM)

In TDM, the data streams are mixed by time slot. TDM is more efficient because the slot assignments can be made flexibly according to the traffic loading on the individual data streams. This is typically used to multiplex digital signals. Most satellite systems multiplex many lower bit rate signals together into a single high bit rate signal using TDM and then combine this with a TDMA scheme.

2.5.9 Single Channel Per Carrier (SCPC)

In SCPC systems, each analog signal is modulated onto its own carrier. SCPC eliminates the need for multiplexing equipment and is easy to reconfigure to meet changing traffic conditions. In SCPC the carrier is only transmitted when the link is active as opposed to FDM where the carrier is always transmitted, thus saving transponder power. FDM however, uses bandwidth more efficiently. SCPC is often used in conjunction with FDMA and DAMA.

3. Present Systems

As of the end of 1997, there were very few options for mobile satellite communications. Argos was the first, starting service in 1978 and is still in use today providing data collection for oceanographic research. Inmarsat, which was formed in 1979 and started providing voice and telex communications service to the maritime community in 1981, has continued to improve and expand services over the years. BOATRACS, the maritime version of OmniTRACS started it's data-only service in 1989 and continues to increase their customer base, primarily in the fleet tracking business. AMSC was the first new Mobile Satellite Service (MSS), launched into orbit in 1995 and started voice and data communications service in the United States in 1996. The last option to be discussed, DirecPC is primarily aimed at fixed sites, but due to the small size of the antenna, can be used by mobile customers with the appropriately gimbaled and tracking antenna. All of these options are summarized in Table 3-1, and discussed in the sections below.

Table 3-1 Current Systems Compared

	Argos	Inmarsat A	Inmarsat B	Inmarsat M	Inmarsat Mini-M	BOATRACS	AMSC	DirecPC
Service Type	Data Only	Analog Voice/Data	Digital Voice/Data	Digital Voice/Data	Digital Voice/Data	Data Only	Digital Voice/Data	Data Only
System Type	LEO	GEO	GEO	GEO	GEO	GEO	GEO	GEO
Coverage	Worldwide	Worldwide	Worldwide	Worldwide	Worldwide	CONUS+ 200–400 NM offshore	CONUS+ 200 NM, AK, HI	CONUS
Frequency Band	UHF	L	L	L	L	Ku	L	Ku
Data Rate	1200 bps (256 bit bursts) (inbound)	9600 bps* or 56 kbps	9600 bps or 64 kbps	2400 bps	2400 bps	600 bps	4800 bps	400 kbps (outbound)
Terminal Cost	Varies, depending upon size and complexity	$25,000–$35,000	$25,000–$35,000	$10,000–$12,000	$5,000	$4,000	$2,500	$300
Monthly Cost	Negotiated	$0	$0	$0	$0	$40	$25	$10–$130
Usage Cost	Negotiated	$3–$8/min	$2–$6/min	$2–$6/min	$3/min	.4¢/char plus 50¢/msg	$1.50/min	$3.95–$4.95 /hour
Antenna Type/Size	Small whip	1m tracking	1m tracking	0.6m tracking	0.2m tracking	.3m" az tracking	1m whip, .3m tracking, .6m tracking	.6m fixed dish
Year Operational	1978	1982	1993	1992	1996	1989	1996	1997

* Speed of Inmarsat A connection depends upon type of modem used, signal strength, and channel quality.
This is also RAW speed. Most modems incorporate V.42/MNP compression.

3.1 Argos

Argos is a satellite-based system which collects, processess and disseminates environmental data from fixed and mobile platforms worldwide[13]. Argos was established under a Memorandum of Understanding (MOU) between the National Oceanic and Atmospheric Administration (NOAA, USA), the National Aeronautics and Space Administration (NASA, USA), and the French Space Agency (CNES, France) and has been operational since 1978. The system is operated and managed by Collecte, Localisation, Satellites (CLS, a CNES subsidiary) in France and Service Argos, Inc. (A CLS subsidiary) in the USA.

Argos provides position location (to within 150–1000 m using Doppler shift measurements) and two-way data transmission worldwide. The data is transmitted from the user to the satellite and then to an earth station. If a regional earth station is in view then the satellite relays the data in real-time, otherwise the messages are recorded on the satellite and then relayed to one of the three main earth stations later.

3.1.1 Ground Segment

There are three main earth stations, Wallops Island, VA, Fairbanks, AK, and Lannion, France that receive all messages recorded by the satellites. The information is then passed on to one of the Global Processing Centers (GPC) that are located in Toulouse, France and Landover, MD. The GPCs process the data, archive it, and make it available to users online. There are also several Regional Processing Centers (RPC) that connect to the GPCs to allow users a more local access point for their data. Some RPCs also connect to Regional Earth Stations that receive satellite data in real-time, and can thus relay data to users in a near real-time mode.

3.1.2 Space Segment

The system currently relies upon two NOAA polar orbiting environmental satellites (POES). These satellites are in sun-synchronous, polar circular orbits, at an inclination of 98°, and have an orbital period of about 102 minutes. They orbit at an altitude of 850 km and have a footprint of about 5000 km in diameter. There are plans to expand the system around the year 2000 by adding the Japanese space agency's ADEOS II satellite and the European Space Agency's METOP satellites.

3.1.3 User Segment

A variety of terminals (known as Platform Transmitter Terminals or PTT) are available ranging in size from 30 to 300 g. PTTs have been developed for diverse applications ranging from tracking migratory birds, to buoy monitoring, ice floe monitoring, and shipboard data. They are all primarily low-power units to allow for long battery life. PTTs transmit their messages at preset intervals autonomously. A message can be up to 256 bits long and can take up to 960 ms

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[13] Argos Web Site, http://www.argosinc.com/.

to transmit, allowing for 5–8 messages per 10 minute satellite pass. All PTTs transmit at a frequency of 401.65 MHz.

3.1.4 Market

The primary customer base for Argos is government and civilian researchers using the system for environmental data collection. This includes things such as tracking fish migration patterns, and ocean current information. There are currently over 5,000 Argos transmitters operating worldwide.

3.2 Inmarsat

The purpose of the International Maritime Satellite Organization (Inmarsat) is to provide satellite-based commercial communications services to ships, aircraft, and other mobile users. The origins of Inmarsat date back to NASA satellite experiments during the 1960's. The World Radio Conference (WRC) in 1971 set the stage by approving the 1.5/1.6 GHz frequency bands for Mobile Satellite Services (MSS). Work then began on a new organization to provide MSS Since the existing International Telecommunications Satellite Organization (Intelsat) did not include MSS in it's charter; Intelsat was chartered to provide fixed satellite services (FSS) only. The primary emphasis was on maritime satellite communications for maritime safety. Inmarsat was thus formed on July 16th 1979 and began operation on 1 February 1982 using transponders leased from MARISAT, ESA (MARECS satellites), and Intelsat.

The Inmarsat organization was patterned after the existing Intelsat organization. Countries join the organization by ratifying the Inmarsat Convention and each country owns a share (and pays) proportional to their usage of the system. There are currently more than 80 member countries. Each government designates an organization or company to be the investor/operator for that country (called a Signatory); the U.S. Signatory is COMSAT. All U.S. Inmarsat service is obtained through COMSAT, which is regulated by the FCC. The FCC also issues licenses for the mobile earth stations (MES). The eighteen largest ownership Signatories plus four others elected on the basis of geographic representation form the governing Council. The day-to-day work is handled by a staff of about 500 called the Directorate. The Inmarsat Headquarters is located in London, UK.

3.2.1 Ground Segment

Inmarsat uses a three-level ground segment. The master Network Control Center (NCC) is located at Inmarsat headquarters in London, UK. Each ocean region then has a Network Control Station (NCS) which assigns channels to users and earth stations within the ocean region. Each ocean region is also served by a number of earth stations. These are called Coast Earth Station (CES) by maritime users, Land Earth Stations (LES) by land mobile users, and Ground Earth Stations (GES) by aeronautical users. The earth station operators link the satellite network to the terrestrial phone, data, and telex networks. They are usually, but not always, Signatories. Each CES connects with one satellite therefore an earth station operator requires four CESs to provide worldwide coverage. Each category of Inmarsat service (defined below) requires an independent set of modulation & processing equipment. Each CES can support one or more services. Earth station operators each establish their own rates and value-added services, which regions to operate in, and which services to support. If the operator is not the Signatory for that country then they pay the Signatory for satellite airtime and the Signatory pays Inmarsat. Transmissions between the CESs and the satellites are at C-band.

3.2.2 Space Segment

Inmarsat provides global coverage between 70°N and 70°S latitudes using four geostationary satellites. Inmarsat splits the world into four ocean regions, with one satellite per region. The orbital slots are listed in the Table 3-2 below. Inmarsat recently upgraded all of their satellites to higher-powered Inmarsat-3 satellites. The last was successfully launched in February 1998.

Table 3-2 Inmarsat Orbital Slots

Ocean Region	Orbital Slot
Atlantic Ocean Region East	15.5°W
Atlantic Ocean Region West	54.0°W
Pacific Ocean Region	178°E
Indian Ocean Region	64.5°W

3.2.3 User Segment

Inmarsat offers a number of different services (described below and summarized in Table 3-3). For each of these, Inmarsat publishes a Systems Definition Manual. Each terminal design is then *type-approved* by Inmarsat. Sales and pricing of the terminals are up to manufacturer. All of the services operate in the same general manner. For MES originated calls, the mobile user selects which CES to use within the current ocean region. The CES then completes the connection through it's terrestrial connections. For shore originated calls, the CES used depends upon agreements by the PSTN operator of which CES to route calls to. In the U.S., calls can be made through COMSAT's CESs by dialing a toll-free number and then the MES number. Transmissions between MESs and the satellite are at L-band.

3.2.3.1 Inmarsat-A

Inmarsat-A was the original service introduced in 1982. It is an analog system that provides voice, data, fax, telex and high-speed data services. There were 20,000 units in service by 1993 and 25,000+ by 1996; 80% of these units are installed on ships. It uses a directional, 1 m parabolic antenna. Maritime units use a tracking antenna within a radome. There are more than 40 CESs worldwide providing Inmarsat-A service. There are at least 15 terminal manufacturers making maritime and land mobile (portable) units. The terminals cost between $25K–$35K with a usage cost of $6–$10 per minute depending upon which CES is used.

3.2.3.2 Inmarsat-B

Inmarsat-B is the digital successor to Inmarsat-A. It was the introduced in 1993 and provides digitized voice, data, fax, telex and high-speed data services. There were 2,000 units in service by February 1996. It uses an antenna similar to that for Inmarsat-A. There were 12 CESs worldwide providing Inmarsat-B service in 1993, and more today. There are at least 10 terminal manufacturers making maritime and land mobile (portable) units. The terminals cost between $25K–$35K with a usage cost of $2–$6 per minute depending upon which CES is used.

3.2.3.3 Inmarsat-M

Inmarsat-M which was also introduced in 1993, was the world's first personal portable mobile satellite phone. It is a digital system that provides voice, data, and fax services. There were 8,500 units in service as of February 1996. It uses a directional 0.6 m parabolic antenna. Maritime units use a tracking antenna within a radome. There are more than 25 terminal manufacturers making maritime and land mobile (briefcase-sized) units. The terminals cost between $10K–$12K with a usage cost of $2–$6 per minute depending upon which CES is used.

3.2.3.4 Inmarsat Mini-M

The launch of the Inmarsat 3 satellites, with high power spot beams, allowed Inmarsat to introduce the Mini-M service in 1996. It operates the same as the regular M service, but the higher power in the spot beams allows the terminals to be smaller and less expensive. By the end of 1996 there were 150 users. The terminals are available in land mobile and maritime versions and are laptop sized. The antenna is also very small, either a flat panel (top of laptop) or a 0.2 m tracking antenna inside a radome for the maritime version. They cost about $5K with a per minute cost of $3.

3.2.3.5 Inmarsat-C

Inmarsat-C was introduced in 1991 and has quickly become the most popular service. There were 5,000 units in service in 1993; this increased rapidly to more than 30,000 in January of 1997. It is a store-and-forward data only system. The MES sends data to the CES where it can either wait in an electronic mailbox to be picked up by a shore customer, or it can be forwarded electronically as packet data, e-mail, or fax. The terminals can also be polled from shore or receive group calls. They come in land mobile and maritime models, are small (3.2 kg) and use small (0.24 m) omni-directional antennas. They cost between $5K–$8K with a cost of about 1¢ per character sent. Inmarsat-C terminals are also used for the reception of maritime safety messages such as Urgent Marine Broadcasts and NAVAREA warnings.

3.2.3.6 Inmarsat-D

Inmarsat-D is a new global paging service that was introduced in 1997. It is not in widespread use yet. It is a one-way data service that allows mobile users to receive and store up to 40 messages of up to 128 characters each. Terminals are expected to cost in the $500–$700 range. Usage costs are not yet available. The next version, Inmarsat D+ will feature terminals that can also transmit short data messages along with position information from an embedded GPS receiver.

3.2.3.7 Inmarsat Aero-C

This is the aeronautical version of the Inmarsat-C service. It operates virtually identical to the standard Inmarsat-C service. The terminals are packaged in standard avionics cases and use an omni-directional antenna inside an aerodynamic radome. Terminal costs are somewhat higher, at $25K but the usage costs are the same as for maritime units.

3.2.3.8 Inmarsat Aero-H

Inmarsat Aero-H was designed to provide simultaneous two-way voice and real time data communications for aircraft. It is a digital system that provides digitized voice, circuit switched and packet data, and fax. Worldwide service is available from 86°N to 86°S. By mid-1993 around 300 aircraft on 29 airlines had terminals with 650+ on-order. There were 1,100 users by

January of 1997. The system is large (40 kg) and complex requiring a tracking antenna housed in an aerodynamic radome. They cost between $150K–$200K with a per minute cost of $5–$8 depending upon which CES is used.

3.2.3.9 Inmarsat Aero-L

Aero-L is a low-gain aeronautical satellite communications system that provides two-way real time data at 600 bps. It is used primarily for airline operational and administrative purposes.

Table 3-3 Inmarsat Services

Inmarsat Service	Year Started	Services	Data Rate	Antenna	Terminal Size	Terminal Cost	Usage Cost
A	1982	Analog voice, fax, data, telex, high speed data	Data: 9.6 kbps / 64 kbps	1m parabolic dish (tracking in radome)	60 kg	$25-$35K	$3–$8/min
B	1993	Digital voice, data, fax, telex, high speed data	Voice: 16 kbps, Data: 9.6 kbps / 56 kbps	1m parabolic dish (tracking in radome)	60 kg	$25-$35K	$2–$6/min
M	1992	Digital voice, data, fax	Voice: 4.8 kbps, Data: 2.4 kbps	0.6M parabolic dish (tracking in radome)	10 kg	$10–$12K	$2–$6/min
Mini-M	1996	Digital voice, data, fax	Voice: 4.8 kbps, Data: 2.4 kbps	0.2m (tracking in radome)	2.5 kg	$5K	$3/min
C	1991	Store-and-forward data, fax	600 bps	0.25m omnidirectional	3.2 kg	$5–$8K	1¢/character
D	1997	Paging	138 characters max	0.1m omnidirectional	0.2 kg	$500-$700	
Aero-C	1991	Store-and-forward data, fax	600 bps	omnidirectional conformal	5 kg	$25K	1¢/character
Aero-H	1990	Digital voice, data, fax	Voice: 9.6 kbps, Data: 10.5 kbps	conformal tracking	40 kg	$150–$200K	$5–$8/min
Aero-L		Digital data	600 bps				

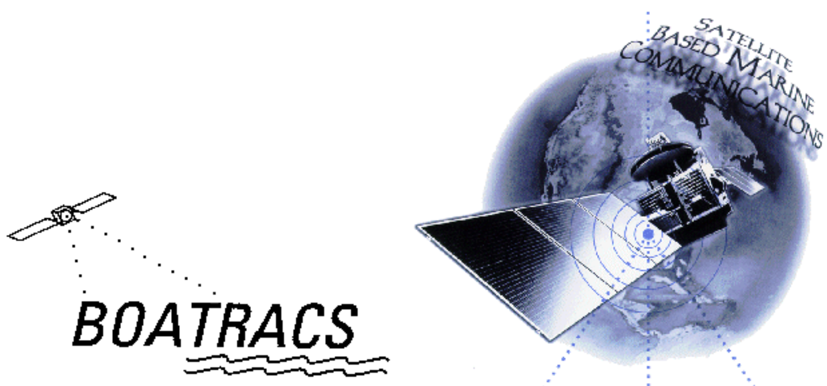
3.2.4 Market

Inmarsat’s principle reason for being organized was to provide maritime safety services. This is provided by many of the Inmarsat services; Inmarsat-A/B/C all satisfy maritime legal carriage requirements under the Global Maritime Distress and Safety System (GMDSS). In addition to maritime users Inmarsat markets their services to aeronautical and land mobile users as well. There is also a fairly large market in transportable units. Currently, Inmarsat is the only commercial service to offer worldwide satellite communications to mobile users. Inmarsat also is currently the only mobile satellite service provider offering or planning to offer a safety service to mariners.

3.2.5 Inmarsat Restructure

In order to compete more effectively with new mobile satellite systems, Inmarsat plans to restructure itself into a private corporation as early as January 1999. Continuation of GMDSS services will be guaranteed by a small intergovernmental organization funded by Inmarsat, until such time as other satellite services offers maritime safety telecommunications services meeting the requirements of the International Maritime Organization.

3.3 OmniTRACS/BOATRACS



“Headquartered in San Diego, CA, BOATRACS Inc. provides two-way satellite-based messaging and vessel tracking services for the commercial marine market, including the workboat, inland and coastal towing, oil supply and fishing industries.”[14] BOATRACS is the maritime distributor for QUALCOMM’s OmniTRACS service. Most of the system is the same as for OmniTRACS, so the references that describe the OmniTRACS system also apply to BOATRACS. BOATRACS however, operates their own message center, and provides many enhanced services that are not available to OmniTRACS users. They market themselves as a total solution provider: hardware, software, and service.

BOATRACS provides two-way data transmission and position location (to within 300 m using triangulation) within the coverage footprint of the Continental United States (CONUS) and 200–400 miles offshore. The user terminals are in continuous contact with the geostationary satellite, which relays messages between the ship and the earth station. Messages are accessed from and sent to the earth station via a variety of terrestrial links.

[14] BOATRACS Web Site, http://www.boatracs.com/.

3.3.1 Ground Segment

QUALCOMM operates two redundant earth stations; the primary in San Diego, CA and the backup in Las Vegas, NV. The Network Control Center and the BOATRACS message center are both in San Diego. Outgoing messages to user terminals are sent as soon as received at the earth station. Incoming messages are kept in a mailbox until the shore terminal connects to the earth station and downloads them. There are also provisions at the BOATRACS message center to route messages via facsimile or the Internet.

3.3.2 Space Segment

QUALCOMM leases Ku-band transponders (currently seven) on existing satellites. Currently service is provided on the G-Star GE-1 satellite. A second satellite is used for the positioning service. Both satellites receive each transmission, and a position is calculated at the earth station from the transmitted signal using a triangulation algorithm. The geostationary satellite provides coverage throughout CONUS and offshore 200–400 miles. Additional coverage is provided in Europe using transponders leased from EUTELSAT.

3.3.3 User Segment

The Mobile Communications Terminal (MCT) consists of three parts: a ruggedized keyboard display unit, a communications unit, and a continuous tracking antenna. The communications unit is capable of transmitting position reports without a keyboard display unit. The keyboard display is used to send and receive text messages. The system also supports the use of macros (templates) to reduce the amount of data being transmitted. BOATRACS also provides software to enable a generic personal computer to interface with the communications unit which provides the capability to send/receive files.

All communications between the MCT and the earth station are at Ku-band. The system has some inherent "security" features in that it uses a combination of TDMA and CDMA for multiple access and Direct Sequence Spread Spectrum modulation.

3.3.4 Market

OmniTRACS currently has approximately 175,000 units in service, primarily installed on tractor trailer trucks. Their primary market is fleet management (messaging and tracking). BOATRACS has a similar market, but within the maritime community. BOATRACS currently has approximately 30,000 units installed on fishing vessels, tugs, and resupply vessels.

3.4 AMSC

American Mobile Satellite Corporation (AMSC) is the single L-band domestic mobile satellite service (MSS) provider licensed by the FCC. They provide low bit-rate voice and data service throughout the continental United States (CONUS) as well as Alaska and Hawaii.

AMSC has it's genesis in NASA's MSAT-X program in the late 1970's and early 1980's. In 1985 the FCC allocated frequencies for domestic mobile satellite service and twelve applications were filed. At WARC 87, the frequencies were allocated internationally. The FCC decided to license only a single domestic MSS and instead of a spectrum sharing arrangement or spectrum auction, they forced the applicants to combine. Eight of the original twelve did so in 1988, and in 1992 the FCC licensed the AMSC consortium.

The Canadian counterpart to this system is the MSAT system owned and operated by Telesat Mobile Inc. (TMI). TMI's satellite, ground network, and user terminals are identical to AMSC's. The original agreements between the two companies called for them to provide backup to each other.

3.4.1 Ground Segment

AMSC operates a single earth station in Reston, VA. This also serves as the network control center. All links into the Public Switched Telephone Network (PSTN) are made through the Reston facility. All calls to mobile terminals are made by directly dialing the terminal's toll-free number. This initiates a call through the PSTN to the earth station and then via the satellite to the mobile terminal.

3.4.2 Space Segment

The original plan was to eventually have three geostationary satellites in orbit. The first at 101°W, then later adding 62°W and 139°W. AMSC launched their first satellite, AMSC-1 in April of 1995 to the slot at 101°W. AMSC currently has control of one other orbital slot, but no plans to launch an additional satellite. In fact, due to slow customer growth, in December of 1997, AMSC signed agreements to lease their satellite to African Continental Telecommunications Ltd. and purchase a 50% interest in TMI. All of AMSC customers will now be served via TMI's satellite, MSAT-1, located at 106.5°W. African Continental will move AMSC-1 to a new location over Africa. TMI might move MSAT-1 to the 101°W orbital slot. Both MSAT-2 and AMSC-1 have 6 L-band spotbeams (AMSC-1 actually only has 5 due to a transponder failure). These enable coverage of CONUS out to 200 NM offshore, and Alaska, Hawaii, and the Caribbean. As with any GEO system, coverage of Northern Alaska is limited since the look angle to the satellite becomes lower than the horizon at high Latitudes.

3.4.3 User Segment

Mobile terminals come in a variety of types and sizes. The main difference between the units is the type of antenna: tracking for vehicle, maritime and aeronautical applications, whip for vehicles, flat panels for portable units, and dishes for fixed sites. Mobile terminals are manufactured by five companies.

- Westinghouse Electric (land mobile and maritime mobile units)
- Mitsubishi Electric (land mobile and maritime mobile units)
- Trimble Navigation (mobile data terminal)
- KVH (maritime units and antennas)
- CALS (aeronautical units)

All units work in the same manner; they function similar to a cellular phone. The user dials a PSTN number directly, the call goes through the satellite, to the earth station, and is connected through the PSTN. Since the system is digital, data connections can be made without the use of a modem. The terminals all have RS232 interfaces to allow external devices such as a computer to connect to the terminal and place a data call.

3.4.4 Market

AMSC currently has about 30,000 customers, mostly concentrated in the vehicle tracking and dispatch market. AMSC's original market was thought to be cellular fill-in, however in the ten years between when the FCC allocated the frequencies and AMSC launched their satellite, cellular systems went through a massive expansion and the cellular fill-in market largely disappeared. Currently AMSC is targeting maritime, aeronautical, emergency communications restoration, search and rescue, SCADA, fleet management and dispatch applications.

3.5 DirecPC

DirecPC

In 1994 Hughes launched their Direct Broadcast Satellite (DBS) television service which they called DirecTV. This Ku-band service utilized high power transponders on the satellite to reduce the required satellite dish size to just 18 inches. This service is a totally digital system using MPEG-2 to compress the audio/video. The success of this system led to the introduction in 1996 of the Ku-band DirecPC system. This is a commercial satellite-based Internet connection service, providing downlink speeds of 400 kbps.

3.5.1 Ground Segment

Hughes Network Systems operates a commercial Network Operations Center and earth station at Germantown, MD. This is the connection between the Internet and the satellite uplink. All traffic outbound to user terminals goes through the NOC to the satellite and is broadcast from the satellite at 12 Mbps.

3.5.2 Space Segment

The DirecPC service was initially carried on one transponder on the Galaxy IV Satellite located at 99°W. Service is now also provided on a transponder of the GE-1 Satellite at 103°W. These satellites provide coverage across CONUS. Unfortunately, the signal strength falls off fairly rapidly offshore, making it difficult to provide service to maritime customers.

3.5.3 User Segment

The user terminal consists of a 21 inch (24 inch originally) elliptically-shaped dish antenna. This connects to a ISA or PCI board that plugs into a Pentium computer using up to 100 ft of RG-6 cable. The ISA board was the original model, and uses the Galaxy IV satellite. The newer PCI board uses the GE-1 satellite. Hughes Network Systems also provides Windows 95 compatible software to enable the computer to use the system.

The user must provide the inbound connection. This can be any type of PPP-based connection to an ISP. Typically this is done via a standard modem connected to the PSTN. However, Inmarsat, cellular, and UHF MILSATCOM connections have been tested. The user can then surf the

Internet, receiving information at 400 kbps over the satellite link, and transmitting requests over the inbound link (speed is dependent upon what is used to make the inbound connection).

3.5.4 Market

This system is marketed and priced for home use. Hughes also markets a network edition for the small office/home office market. Their newest offering is a combination DirecPC and DirecTV system called DirecDuo.

4. Available Soon (1998-2000)

During the two-year period 1998–1999, several new satellite systems will come on-line. Two "little LEO" data-only systems, VITAsat and ORBCOMM will become fully operational. As of the time of writing, both of these systems already have satellites on-orbit and are offering some service. The first two "big LEO" or voice/data systems will start service in this time period. Both Iridium and Globalstar already have satellites on-orbit and will complete their constellations in 1998–1999. There are two high speed data systems, CyberStar and Turbosat, that will start service in this time period. Both of these GEO systems will start service using transponders on existing satellites. The final system discussed in this section, GBS, is a system that is being developed by DoD for military use. All of these systems are summarized in Table 4-1, and discussed in detail in the sections below.

Table 4-1 Systems Available 1998–1999 Compared

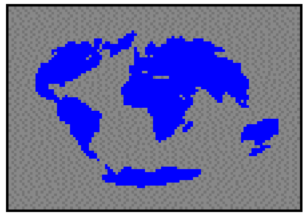
	VITAsat	ORBCOMM	Iridium	Globalstar	CyberStar	Turbosat	GBS
Service Type	Data Only	Data Only	Digital Voice/Data	Digital Voice/Data	High speed Data	High speed Data	High speed Data
System Type	LEO	LEO	LEO	LEO	GEO	GEO	GEO
# Satellites	2	36	66	48	1/3**	1+	Phase I: 2 Phase II: 3 Phase III: 5
Altitude (km)	1000	825	780	1414	35,786	35,786	35,786
Coverage	Worldwide	Worldwide	Worldwide	Worldwide	Worldwide	CONUS	Worldwide
Frequency Band	VHF	VHF	L	L	Ku/Ka**	Ku	Ku
Data Rate	9600 bps	2400 bps xmt 4800 bps rcv	2400 bps	9600 bps	30 Mbps (rcv only)	64 kbps–1.7 Mbps (xmt) 2-20 Mbps (rcv)	23 Mbps (I) 1.544 or 24 Mbps (II) (rcv only)
Terminal Cost	$3,500	$250–$1,500	$2,000– $3,000	$750	unknown	unknown	Free***
Monthly Cost	$50*	unknown	$50	$0	unknown	unknown	Free***
Usage Cost	Flat rate	unknown	$1.75/min + long distance charges	35¢–50¢/min	unknown	unknown	Free***
Antenna Type/Size	RHCP omni or tracking	omni whip on hand-held terminal	omni whip on hand-held terminal	omni whip on hand-held terminal	0.9 m dish	0.47–2.4 m dish	0.47 m dish
Year Operational	1998	1998	1998	1998	Fall 1998/ 2000**	1998	2000 - I 2006 - III

* Free for humanitarian organizations.

** Initial service to start in 1998 using existing Ku-band transponders. Ka-band service to start in 2000.

*** DoD funded service.

4.1 VITAsat



"Volunteers in Technical Assistance (VITA) is the first private voluntary organization to apply advanced micro-electronics and space technology to the dissemination of technical information for development and humanitarian purposes."[15] For the past 34 years VITA has been helping people in developing countries improve the quality of their lives by providing information services. VITAsat is one component of the global communications system called VITACOMM that VITA has developed. VITAsat is designed specifically for developing countries.

VITAsat is low-earth orbiting (LEO), data-only, satellite system. When a ground station is within the footprint of the satellite, the station can retrieve or transmit messages. The VITAsat satellite is a store-and-forward system, first storing the messages form the ground station and then forwarding them to their respective destinations. Once the LEO receives a message, it can forward it to the proper destination in under 12 hours.

VITA recently announced a partnership agreement with SatelLife to combine the VITAsat and HealthSat II networks to create a global e-mail system dedicated to humanitarian and development purposes.

4.1.1 Ground Segment

VITA linked their satellite system to the Internet in 1993. They currently use earth stations and Internet gateways in five countries: Norway, South Africa, Australia, Chile, and Canada. The network control station will be located in Logan, Utah. The earth stations/Internet gateways receive messages from the satellites as they pass overhead and forward them along the Internet. They also store messages received from the Internet until the satellite is in view, and then transmit them to the satellite for delivery to the field.

4.1.2 Space Segment

VITA has been experimenting with LEO satellites since 1984. Their prototype was launched in 1990 and used by many organizations until it failed in early 1997. Some traffic was then transferred to the Portuguese PoSat-1. VITAsat-1 was successfully launched on 23 Sep 1997 as a secondary payload on FAIsat-2v. It is currently undergoing testing with service anticipated to start in early 1998. VITA has FCC authorization to build and launch a second satellite.

Recognizing that two satellites do not provide sufficient coverage, VITA has proposed the creation of a coalition of LEO satellite systems. Linking the various systems would allow for more coverage for users than a single system alone could provide. This Internet related communications network would provide cheap and reliable access to critical health, education, and disaster information to people in developing countries.

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[15] VITA Web site, http://www.vita.org/.

4.1.3 User Segment

A new series of mobile terminals or ground stations is being developed to work with the new VITAsat satellites. These will be highly portable in nature, requiring only that a laptop computer be attached. They are expected to cost about $3,500 with service being a flat rate of $50/month for 100 KB of data. VITA plans to provide free communications service on it's VITAsat-1 to non-governmental organizations engaged in humanitarian and developmental activities around the world.

4.1.4 Market

VITA's market is to provide communications to developing countries for such things as disaster mitigation, prevention, and response; health education and information; vehicle tracking; data gathering and dissemination; and administrative and logistic support. VITA's goal is to bring under-served areas of the world into the mainstream. As VITA's President Henry Norman has said: "Development cannot take place without communication, and in the information age, communication can't take place without information."[16]

4.2 ORBCOMM

ORBCOMM
GLOBAL DATA & MESSAGING

ORBCOMM is a mobile satellite service provider offering high value, two-way data and message communications globally through international service licensees and in the U.S. through value-added resellers, as well as through direct sales.[17] Since ORBCOMM has offered commercial service on two satellites since 1996, they could have been included in the previous section for systems available now. However, since with only two satellites the service has been limited to about 90 minutes per day, and with the full constellation going into service in mid-1998, they have been included in this section.

ORBCOMM is a data-only LEO satellite system. They will offer worldwide coverage in both "real-time" and store-and-forward modes. When the user terminal or Subscriber Communicator (SC) is not within range of a Gateway Earth Station (GES), the satellite will store messages and forward them when it passes over a GES. When both the SC and the GES are within the satellite footprint, the system operates in "real-time" mode, with an end-to-end transmission time of about 5 seconds.

The ORBCOMM system will provide the following services: tracking, monitoring, commercial messaging, and personal messaging. The system transmits and receives small packets of data. The Subscriber Communicators also automatically report their position using either the inherent Doppler position calculation, or GPS position if the user terminal is equipped with an embedded GPS receiver.

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[16] VITA Web site, http://www.vita.org/.

[17] http://www.orbcomm.net/ncc/countdown.html.

4.2.1 Ground Segment

For "real-time" operation ORBCOMM satellites operate in a "bent-pipe" mode, which means that the user terminal and a Gateway Earth Stations (GES) both need to be within the satellite footprint. ORBCOMM plans to cover the United States using four Gateways, located in Georgia, New York, Arizona, and Washington. These GESs will be unattended stations that make the RF connection to the ORBCOMM satellites, transmitting and receiving data at 56.7 kbps (total bandwidth for satellite. The GESs are all connected via landlines to the Network Operations Center (NOC) which provides the interfaces to terrestrial networks. A variety of standard access modes will be provided including X.400, X.25, leased line, dial-up modem, PSDN, and e-mail.

4.2.2 Space Segment

The ORBCOMM constellation will consist of up to 36 small low earth orbit (LEO) satellites orbiting at 825 km. The first two satellites were launched into near-polar orbit on 3 April 1995. These two satellites were used for testing and initial commercial service; they will probably be retired. Twenty-four satellites will be launched into circular orbit, in three planes of eight satellites each. The first eight of these were launched in December 1997. The other two planes will be launched in 1998. An additional two satellites were launched into near-polar orbit in February 1998. The full constellation of 28 is scheduled to be online by July 1998. ORBCOMM also has the option of launching an additional eight satellites, if there is sufficient demand. These are planned to be launched into a circular orbit about the Equator.

ORBCOMM has plans to use two different launch vehicles. Their own Pegasus launcher can carry eight satellites into orbit. Orbital Science's Taurus rocket can lift two satellites to orbit.

4.2.3 User Segment

ORBCOMM has commissioned several terminal manufacturers. They will be making models for different markets with various capabilities. Some will have embedded GPS receivers for enhanced positioning, others will have keypads and displays, and some are "black boxes" for SCADA applications. The terminals will range in cost from $250 to $1,500. All operate in the VHF band using a small whip antenna. They transmit data to the satellite at 2400 bps and receive at 4800 bps. Usage rates are not known at this time.

4.2.4 Market

ORBCOMM plans to provide customers the ability to send and receive short messages from anywhere on Earth. Their target industries include transportation, marine, oil and gas, and defense. Applications include industrial asset monitoring and control, SCADA, cargo tracking, tracking of mobile assets such as trailers, rail cars, and shipping containers, two-way messaging for commercial, military, and recreational markets.

4.3 Iridium

Engineers at Motorola's Satellite Communications Group conceived the Iridium System in 1987. Motorola filed an application for the system with the FCC in 1990 and in 1991, Iridium, Inc. was established as a separate company to develop and deploy the satellite network. In the past decade, the program has achieved a multitude of milestones, which have turned what was once considered a far-fetched concept into a very real, revolutionary system — one that changes the future of global wireless communications.[18] Iridium will be the first "big" LEO system in operation with service set to begin on 23 September 1998. It is an all-digital system providing digitized voice or data at 2400 bps. They plan to offer the following services:

> **Iridium World Satellite Service.** This service provides a direct satellite link for both incoming and outgoing communications. A single telephone and a single telephone number will provide global accessibility.
>
> **Iridium World Cellular Service.** This service will offer a simple solution for incompatible cellular networks, multiple phone numbers, and separate charges by enabling users to roam onto incompatible wireless networks while maintaining a single telephone number. Users will be automatically registered on the local cellular telephone network with the same telephone number as on the home system. Calling charges in every city will be consolidated on the regular cellular bill.
>
> **Iridium Universal Service**. This service combines global satellite coverage with local cellular services. It is a combination of the two services described above. When subscribers are within the coverage area of terrestrial wireless, even if the location has a different cellular standard, calls will be handled by the ground-based infrastructure. Otherwise, calls will be handled by the Iridium satellite network. Subscribers will use one phone, with one telephone number, and receive a single monthly invoice from their service provider.
>
> **Iridium Paging and Global Notification Service.** The optional WorldPage Service will provide alpha or numeric messaging to a belt-worn pager. Paging will be available with any of the voice services described above, or as a standalone service. Global Notification Services, another optional paging service, will allow callers to leave either voice-mail or numeric messages when calling an inactive subscriber terminal.

4.3.1 Ground Segment

Iridium gateways will be located in key regions of the world. There are twelve planned for the first three years, and ten are complete. The U.S. gateway is located in Tempe AZ. These gateways will be owned and operated by Iridium, Inc. investors. In addition, the DoD has recently signed an agreement with Iridium to purchase service and a gateway which will be located in Hawaii. The System Control and Master Control facility will be co-located in Leesburg, VA. Three TT&C (Telemetry, Tracking, and Control) centers located in Hawaii and Canada are linked directly with the master control facility to monitor satellite positions on-orbit.

The Iridium gateways will connect the Iridium constellation with the PSTN. Satellite to gateway links are in the Ka-band. At the heart of the gateway is a Siemens EWSD-based D900 switch. This switch is based on the GSM (Global System for Mobile Communications) cellular standard

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[18] http://www.iridium.com/company/projhist.html.

and enables seamless integration of Iridium services with land-based telecommunications systems.

4.3.2 Space Segment

The Iridium constellation will be made up of 66 satellites. The original constellation plan called for 77 satellites, hence the name Iridium after the atomic element with 77 electrons. The satellites will be placed into near-Polar, circular orbits at an altitude of 780 km. The constellation is divided into 6 planes oriented at an inclination of 86.4° with 11 satellites per plane. Iridium also plans to launch one spare satellite per plane, for a total of 72 satellites.

Each Iridium satellite weighing approximately 689 kg, will cover a footprint of 4700 km using 48 beams. Iridium is also unique among the first wave of new systems in that they will be using intersatellite links (at Ka-band). Each satellite will have connections to the four adjacent satellites (ahead, behind, and to either side). These links allow a call to be made from anywhere, and routed satellite to satellite and then to a gateway.

Iridium launched their first satellites on 5 May 1997. During 1997 there were a total of nine launches, all successful: two on the Russian Proton carrying 7 satellites each, six Boeing Delta's carrying 5 satellites each and one Chinese Long March carrying 2 satellites. Two of the satellites failed in orbit for a total of 44 operational satellites. There have been 4 launches to date in 1998: on 18 February and 30 March, Delta boosters launched 5 satellites each, and on 25 March, 2 satellites were launched using a Long March 2 booster. The latest launch on April 6, 1998, put 7 more satellites into orbit aboard a Proton rocket from the Baikonur Cosmodrome in Kazakhstan, bringing the number of satellites to 63. The constellation will be completed with two more launches scheduled for late April, 1998, aboard a Delta II and a Long March 2C/SD rocket.

4.3.3 User Segment

Iridium plans to have small cellular phone sized handsets. These will be produced in two dual-mode (cellular and satellite) versions (IS-41 and GSM cellular versions). The handsets communicate with the satellites at L-band. The handsets operate in a half-duplex mode; the same frequencies are used for both transmit and receive. Each 90 ms time division multiplex (TDM) frame has 4 slots for uplink and 4 for downlink. Digitized voice and data are both transmitted at 2400 bps. The handsets will have standard RS-232 ports for data and fax transmissions. Terminals are expected to cost $2,000–$3,000 with usage costs of $50/mos. and $1.75/min. plus long distance charges.

4.3.4 Market

Iridium's stated mission is to provide the highest quality worldwide telephony service for the international business traveler. The service will combine the best of cellular and satellites on one phone with one number anywhere in the world. In addition to international travelers, Iridium also plans to market their service for general aviation, rural telephone, corporate customers, and the government. They have done extensive market research and expect the addressable market to be more than 42 million subscribers out of a projected wireless subscriber market of 500 million by 2005.

4.4 Globalstar

Based in San Jose, California (USA), Globalstar is a Limited Partnership company formed in 1991 by a consortium of the world's leading telecommunications companies to develop, launch, and operate the Globalstar LEO satellite communications system. Founded by Loral Space & Communications, Ltd. of New York City, and QUALCOMM Incorporated of San Diego, California, Globalstar's strategic partners include: AirTouch Communications, DACOM/Hyundai, France Telecom/Alcatel, Daimler-Benz, Vodafone, Alenia Spazio, Elsag Bailey, and FINMECCANICA.

The Globalstar system is a satellite-based, wireless telecommunications system designed to provide voice, data, fax, and other telecommunications services to users worldwide. Users of Globalstar will make or receive calls using hand-held or vehicle mounted terminals similar to today's cellular phones. Calls will be relayed through the Globalstar satellite constellation, in a 1414 km orbit above the Earth, to a ground station, and then through local terrestrial wireline and wireless systems to their end destinations.[19] All calls enter the service provider's land-based network. AirTouch has been selected as the sole US service provider. They expect to start commercial service in early 1999.

4.4.1 Ground Segment

The Globalstar ground segment consists of the Gateways, the Ground Operations Control Center (GOCC), Satellite Operations Control Center (SOCC), and the Globalstar Data Network (GDN). There will be approximately 60 gateways worldwide; currently there are 38 under contract. The U.S. gateway is located in Clifton, TX. The Gateways interconnect the satellites with the PSTN and the PLMN (either AMPS or GSM). The GOCC is responsible for the communications schedules for the Gateways and allocates satellite resources to each Gateway. The Gateways communicate with the satellites at C-band. The SOCC provides TT&C services for the satellite constellation. The GOCC and SOCC are located in San Jose, CA. The GDN is the wide-area network which interconnects the Gateways, the GOCC, and the SOCC.

4.4.2 Space Segment

Globalstar will provide global coverage from 70°S–70°N with a constellation of 48 satellites in circular orbits at 1414 km. These will be divided into eight planes inclined at 52° of 6 satellites each. In addition, eight on-orbit spares will be placed into a lower (920 km) parking orbit. Globalstar will initiate service with a 24 satellite constellation.

Globalstar launched their first four satellites on 14 February 1998. The next launch is scheduled for April, with a total of 44 satellites scheduled to be launched in 1998. Globalstar will use three different launch vehicles to place their satellites in orbit: the Boeing Delta 2 and the Starsem Soyez which each carry 4 satellites, and the Yuzhnoye Zenit-2 which can carry 12 satellites.

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[19] Globalstar web site, http://www.globalstar.com/.

Globalstar satellites operate in a “bent-pipe” mode, relaying signals between user terminals and the Gateway without any processing. The satellites use a CDMA/FDMA multiplexing scheme. Each satellite weighs 450 kg and uses 16 spotbeams to cover a 5,800 km footprint on the Earth.

4.4.3 User Segment

Globalstar also plans to have small, cellular phone-sized handsets. They have contracted with several manufacturers to produce user terminals in three versions, fixed, mobile, and personal. The fixed unit is a specialized version to connect a standard pay telephone to the PSTN and will be used to provide phone service to rural areas and undeveloped countries. The mobile unit is a vehicle mount version of the personal. The personal user terminal is a small hand-held device which will be available as a Globalstar/GSM dual-mode unit or a Globalstar/AMPS/IS-95 tri-mode unit. These units will allow users to switch between terrestrial cellular and satellite modes depending upon coverage. Terminals are expected to cost about $750 with a usage charge of $0.35–$0.50 per minute.

Subscriber Terminals will operate with single satellite or with up to three satellites simultaneously for path diversity. Path diversity is a patented method of signal reception that permits the combining of multiple signals of varying power strengths into a single coherent signal. Typically, two to four satellites will be in view at any time. As satellites are constantly moving in and out of view, they will be seamlessly added to and removed from the calls in progress, thereby reducing the risk of call interruption. This will enable the Globalstar system to provide service to a wide variety of locations, with less potential for signal blockage from buildings, terrain or other natural features.[20]

Globalstar Subscriber terminals provide digital voice and data services. Voice is digitized using a variable rate VOCODER operating at rates of 1,200 (idle) up to 9,600 bps. Data is transmitted at 9600 bps. Communications between the Subscriber Terminals and the satellites uses L-band for the uplink and S-band for the downlink.

4.4.4 Market

Globalstar’s goal is to provide low-cost, high quality services to areas currently under-served or not served at all by existing wireline and cellular systems. Their business model is to provide low-cost, user friendly service, worldwide, with universal roaming using existing service providers as partners. Their primary markets are national subscribers out of range for local cellular, rural fixed service, and vehicles. International roamers (business travelers and tourists) are a low priority. They expect to have 3 million subscribers with an average of 1900 annual min/subscriber by 2002.

4.5 CyberStar

[20] http://www.globalstar.com/tech/tech.htm#pathdiv.

CyberStar is a new broadband digital services provider formed by Loral. They will provide high-speed data, Internet access, multimedia, and data and video streaming at up to 30 Mbps to personal computers. They will provide these services using a hybrid system of geostationary satellites and terrestrial networks. It is designed to be an open network protocol system to offer small offices and homes affordable high-speed Internet access as well as provide private network services for the Enterprise. The Enterprise market rollout is scheduled for the Fall of 1998 with Consumer rollout to follow in the Spring of 1999.

4.5.1 Ground Segment

CyberStar plans to operate a single Network Operations Center (NOC), to be located in the Silicon Valley, CA. The NOC is the connection between the satellite and the terrestrial networks; both the Internet and private networks. In addition the NOC can receive information on CD, tape, or disk.

4.5.2 Space Segment

CyberStar plans to offer service starting in the Fall of 1998 using a hybrid network of leased Ku-band satellite transponders (on Telstar 5) and terrestrial connections. Service will transition to Ka-band in 2000. CyberStar has orbital slots for Ka-band at 93°W, 115°W, and 105.5°E. In addition, CyberStar plans to link with Alcatel's SkyBridge system in 2002. Information will be distributed from the satellites in multi-cast mode.

4.5.3 User Segment

CyberStar has announced an agreement with Adaptec to produce satellite-to-PC receiver boards; the Satellite Express ABA-1040. This teaming pairs CyberStar's smart card and encryption software with Adaptec's PCI-based computer adapter. This is connected to a 0.9 m dish to enable the user to receive information at up to 30 Mbps. The user must also have a separate ISP connection for the return link (similar to the DirecPC system).

4.5.4 Market

The target markets for this system are Enterprise networks as well as the Small Office / Home Office(SOHO) market. In addition, CyberStar will target consumers who would like high-speed Internet access. Pricing information is not available at this time.

4.6 Turbosat

Turbosat is a new satellite service to be offered by GE Capital Spacenet starting in June of 1998. This service is a high-speed VSAT system using geostationary Ku-band satellites. It will provide two-way, high speed data, for point-to-point connections as well as Internet connections.

4.6.1 Ground Segment

GE Spacenet has not released many details of the system yet, but it is primarily a point-to-point VSAT service.

4.6.2 Space Segment

Service will be offered using GE Americom's Ku-band satellites. GE Spacenet uses proprietary Forward Error Correction (FEC)and encoding to maximize throughput and conserve bandwidth. In addition the Turbosat service will make use of TCP/IP "spoofing" to improve TCP/IP network performance.

4.6.3 User Segment

Turbosat terminals use CDMA modulation to enable transmission using small satellite dishes at Ku-band. There will be three dish sizes, a 0.47 m to provide service up to 64 kbps, 0.67 m for 128 kbps capability, and a 2.4 m for the maximum, 1.7 Mbps data rate. Initially, data will be received by the terminals at 2 Mbps, with an increase up to 20 Mbps later.

4.6.4 Market

GE plans to market their system to traditional VSAT customers such as Point-of-Sale and ATM services. They are also looking to attract customers who currently use landline services.

4.7 GBS

The Global Broadcasting System is a Department of Defense system used to send large amounts of data into the field. It will provide fixed and mobile US forces deployed world wide with a dedicated high data rate simplex communications broadcast. It will integrate seamlessly as part of the future MILSATCOM architecture. It will also reduce the communication loads on other DoD two-way channels.

The system development is broken down into 3 phases. Phase One is a proof of concept system that uses a leased transponder and provides CONUS coverage (1996–1998+). Phase Two is the installation of GBS Ku-band transponders on three DoD UHF follow on (UFO) satellites (1998–2006+). Phase Three of the system is the addition of more satellites. Phase Three of the system should be fully operational around 2006.

4.7.1 Ground Segment

The ground segment for each satellite is a Primary Injection Point and a Theater Injection Point. The Primary Injection Point is a fixed earth station that injects RF streams to a specific satellite. The Theater Injection Point is a transportable Primary Injection Point that can be used in the field to inject theater specific data. The Theater Injection Point can be installed on a mobile platform such as a ship. All data to be broadcast to the field is routed to one of the injection points, where it is uplinked to the satellite.

4.7.2 Space Segment

Phase One of the system currently uses leased Ku-band transponders on 2 commercial satellites for proof of concept testing. One satellite provides CONUS coverage and one provides coverage over Europe. One transponder is capable of providing 23 Mbps data transfer to an antenna the size of those used for DirecTV. Phase Two of the system will consist of GBS transponders on each of the next three UHF follow on satellites. (UFO 8,9,10). The transponder packages include two K-band uplink antennas and three Ka-band downlink spot beams. Each of these satellites provides coverage to approximately 1/3 of the earth (there is no Phase Two coverage over central CONUS). Each of the transponders on these satellites will have 3 steerable spot beams. One beam has a footprint of 3,660 km and provides a data rate of 1.544 Mbps. The other 2 spot beams each have a 915 km footprint and provide a data rate of 24 Mbps (see Figure 4-1 below). It takes approximately 3 minutes to move a spot beam from one location to another. UFO 8 was launched on 16 March 1998. UFO 9 is scheduled for launch in October 1998, and UFO 10 in January 1999. Phase Three of the system calls for the addition of more satellites though the exact configuration has not been determined yet.

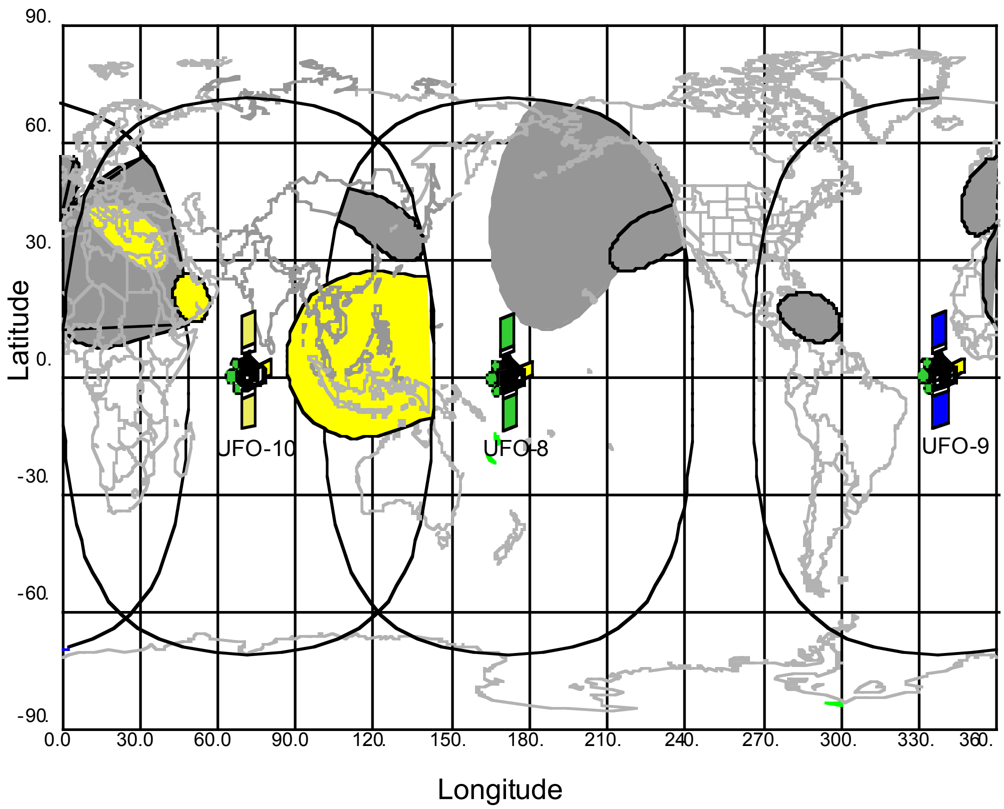

Figure 4-1 Phase Two GBS Coverage

4.7.3 User Segment

The user equipment is based on DBS DirecTV equipment. Phase One shipboard applications consist of a COTS 1 m Seatel dish antenna. The below-deck equipment consists of a receiver approximately the size of a VCR and a UNIX computer. The system provides a high bandwidth one way channel to the field. Any type of data can be sent over this channel such as message traffic, air tasking orders, imagery files, weather, news, or broadcast video. The Phase Two shipboard system will use a Windows NT computer.

4.7.4 Market

Not applicable. This system is owned and operated by the Department of Defense.

5. Turn of Century (2000-2001)

Another seven satellite systems are planning to start service starting in 2000–2001. Three of these, E-SAT, FAISAT, and LEO One are the “Second Round” little LEOs. So-called because they were in the second round of FCC licensing for the little LEO spectrum. The FCC finally issued their ruling on this Second Round late in 1997, and these three systems were the license recipients. There are also three big LEO systems in this grouping: ECCO, Ellipso, and ICO. Both ECCO and Ellipso had been waiting for their FCC licenses to proceed, but have recently received their authorizations. This was issued in late 1997. ICO, plans to use the S-band which has been authorized internationally, but has not been approved for use in the U.S. by the FCC. The last system to be considered in this group, SkyBridge is a broadband (defined below in Section 6.0) system. It is the only broadband data system to propose using the Ku-band. If they hold to their schedule, they will also be the first broadband satellite data system in operation. All of these systems are summarized in Table 5-1 below, and discussed in detail in the sections below.

Table 5-1 Systems Available 2000–2001

	ECCO	Ellipso	E-SAT	FAISAT	ICO	LEO One	SkyBridge
Prime Company	Constellation Communications, Inc.	Mobile Communications Holding Inc.	E-Sat, Inc.	Final Analysis, Inc.	ICO Global Communications	LEO One USA	SkyBridge L.P.
Service Type	Digital Voice and Data	Digital Voice and Data	Data Only	Data Only	Digital Voice and Data	Data Only	Broadband
System Type	MEO	MEO/HEO	LEO	LEO	MEO	LEO	LEO
# Satellites	46	17	6	38	10	48	64
Altitude (km)	2000	8063 / 520–7846	1260	1000	10,355	950	1457
Frequency Band	L/S	L/S	VHF/UHF	VHF/UHF	S	VHF/UHF	Ku
Data Rate	2400 bps	9600 bps	2400 bps?	19.2 kbps xmt 128 kbps rcv	38.4 kbps	2400 bps xmt 4800 bps rcv	2 Mbps xmt 20 Mbps rcv
System Cost	2.9–4 B	750 M	49 M	200 M	2.6 B	500 M	3.5 B
Year Operational	2001	2001	2000	2000	2000	2001	2001

5.1 ECCO

ECCO, by Constellation Communications, Inc. will be a LEO satellite based system that will provide digital voice, data and fax from fixed and mobile platforms worldwide. It will operate similar to a cellular phone system. The system will be implemented in two phases. The first phase will provide a single orbital plane around the equator and provide services to the Earth's tropical regions from 23° N to 23°S Latitude. This portion of the system is scheduled to be on line in 2001. The second phase of the system will add seven high inclination orbital planes and increase the coverage area to 70°N to 70° S Latitude. This portion of the system is scheduled to be operational by 2003.

5.1.1 Ground Segment

The ground segment will consist of a primary and back-up Satellite Maintenance Facility (SMF) and Gateway Earth Stations. The SMF will act as the TT&C facility. The SMF will also monitor the satellite constellation geometry and individual spacecraft status and determine what adjustments are needed. The SMF will communicate with the satellites through the gateway sites.

The gateway earth stations will connect the satellite system with the Public Switched Telephone Network (PSTN). The Gateways will acquire and track the satellites and provide voice, data, and fax interfaces with the PSTN. They will perform user authentication and channel assignment, support billing, receive satellite telemetry data, and transmit commands to the satellites. The gateway will use uplink and downlink frequencies in the C-band. The satellites in the inclined orbits will also have a gateway to satellite feeder link at Ku-band. Each gateway will have three steerable 6 m diameter dishes. One antenna will track the rising satellite, one will track the setting satellite, and one will be a spare. Additional antennas may be added to extend the service area. Each satellite may be accessed by more than one gateway at the same time.

5.1.2 Space Segment

The system will be composed of 46 operational and 8 spare satellites orbiting in 8 planes. They will be in a circular orbits at 2,000 km with an orbital period of 127 minutes. The system will be implemented in 2 phases. The first phase will provide a single orbital plane around the equator. This plane will have 11 operational satellites and 1 spare. Each of these satellites will have 24 spot beams that will allow each satellite to cover 46° of Latitude and 33° of Longitude. This portion of the system is scheduled to be online in 2001.

The second phase of the system will consist of 7 high inclination orbital planes. Each of these planes will contain 5 operational and 1 spare satellite. Each of these satellites will have 32 spot beams. This phase of the system is expected to be operational by 2003. The system will use a CDMA (code division multiple access) multiplexing scheme.

5.1.3 User Segment

The user terminals will consist of hand-held mobile units, vehicle mounted mobile units, and fixed site units for home, office or public pay phone usage. The mobile user terminals will use non-directional antennas. The typical transmit power will be below 1 watt but it can be increased as high as 3–5 watts if needed. The fixed user sites will have steerable antennas. The system will also have dual-mode mobile terminals that can use a cellular phone system when one is available and switch to the satellites when it is not. The system will support data at 2,400 bps. The downlink frequency to the user terminals will be at S-band and the uplink frequency from the user terminals will be at L-band.

5.1.4 Market

ECCO’s market is to provide affordable telephone services to rural and remote areas where the high cost of terrestrial infrastructure cannot be justified because of low population densities. It will act as a "telecommunications bridge" between the rural areas and the existing telecommunications infrastructure. The space segment, including TT&C, will be owned and operated by Constellation Communications and its partners. They will sell the satellite air time to independently owned and operated Gateway Operators in the host nations. The Gateway Operators will sell the service directly or through local service providers. User terminals are expected to cost between $750–$1,000.

5.2 Ellipso

Ellipso is a MEO satellite system. It will provide low cost telecommunication services in areas of the world with insufficient infrastructure. Services will include: digital voice, 300–9600 bps data, fax, paging, voice mail, messaging, and positioning. Ellipso is intended to complement existing telephone and data networks and service will be priced comparable to local cellular calls. The system will use 17 satellites and 3 spares. It will use wideband Code Division Multiple Access (CDMA) transmission method. It is scheduled to begin operations in 2001 and be fully operational by 2003.

5.2.1 Ground Segment

The ground segment is composed of several components. The first is the Ground Control Stations (GCS). These are the ground to satellite interface points. They are analogous to a cellular system cell site. The second component is the Ellipso Switching Office (ESO). The ESOs handle all the switching and routing for the ground portion of the Ellipso system. The ESO also interfaces with the local PSTN. It is similar to a Cellular Mobile Telephone Switching Office. It will use the same standards and protocols as cellular and support Signaling System 7 (SS7) and X.25. The third ground segment component is the Regional Network Control Center (RNCC). The RNCC is the central network planning, management, and accounting facility for each market served. The fourth component is the Ellipso System Coordination Center (SCC). The SCC handles global system planning and allocation. It is the central clearinghouse for all call transactions; it maintains a master database of all subscribers; and it coordinates routing for internationally roaming subscribers. The fifth component is Ellipso Tracking, Telemetry, and Command Center (TTCC). The TTCC monitors and controls the function and integrity of the satellites, their orbits, and their payloads.

5.2.2 Space Segment

Ellipso uses Apogee Pointing to the Sun (APTS) orbits which maximizes satellite time in daytime coverage areas. The system is designed to match capacity more closely to the earth's distribution of population and landmass and is divided up into two constellations. The northern temperate latitudes are covered by the Ellipso-Borealis constellation. This constellation is made up of 10 satellites in two elliptical orbit planes having orbital periods of three hours. The apogees are 7,846 km and the perigees are 520 km. The apogees are near the northern extremity of the orbits. The Ellipso Concordia constellation serves areas in the tropical and southern latitudes. It is made up of 6 satellites in a quasi-circular equatorial orbit at an altitude of 8,040 km and 4 satellites in an elliptical orbit. These orbits will enable users in the most populated latitudes to have average elevation angles of 40-60°for the primary satellite.

The 650 kg satellites are the simple transponder type. Their primary purpose is to connect the subscriber to the Ground Control Station. Communications between the GCC and the satellites will be at C-band. The satellites each have 61 spotbeams which provide a footprint of 11,960 km.

5.2.3 User Segment

Ellipso will offer hand held, mobile and fixed terminals. The user terminals will be similar in form and functionality to cellular phone technology. The hand-held phones will be similar in size, weight, and output power to pocket cellular phones. Mobile vehicle terminals will be optimized for moving vehicles. Fixed sites will be optimized for excellent service and high system capacity. The mobile terminals have omni-directional antennas, the fixed sites have steerable antennas. Some terminals will be dual mode; they will be able to use either the terrestrial cellular system or Ellipso. Ellipso will also support specialized terminals such as data-only, personal digital assistants, paging and polling terminals. The mobile uplink frequency is at L-band and the downlink frequency is at S-band.

5.2.4 Market

Ellipso is predicted to have the lowest cost-per-billable minute of the LEO systems enabling it to offer inexpensive service. Ellipso is thus expected to be ideal for developing countries seeking to expand or initiate telecom services without investing in cost prohibitive infrastructure. Many rural areas of the world are not served by any type of phone service. The cost of mobile service is expected to be $35.00/month and $0.50 /minute. The fixed site prices are expected to have no monthly charges and have prices as low as $0.12/ minute. Ellipso will offer free air time to international relief organizations. Ellipso has indicated that it could capture 7% of an estimate $20 Billion market, or 1.35–1.75 million subscribers by 2005.

5.3 E-SAT

E-Sat is one of the second round of little LEO systems to be licensed by the FCC. It is owned 80% by Echostar communications and 20% by DBS Industries. It is a data-only LEO satellite system that will provide store and forward messaging. The primary coverage area will be North America. It is expected to be operational in 2000.

5.3.1 Ground Segment

No information is yet available about the E-SAT ground segment.

5.3.2 Space Segment

The system will consist of six LEO satellites orbiting at 1,260 km. They will be arranged in two orbital planes of three satellites each inclined at 100°.

5.3.3 User Segment

User equipment will consist of a utility meter with integrated satellite radio and antenna under the cover. The meters are manufactured by ABB and the integrated radio equipment is manufactured by Seimac Limited.

5.3.4 Market

Global Energy Metering Service, Inc. (owned by DBSI) will provide a service to utility companies. It will remotely collect, validate, format, and electronically deliver energy data to the utility to expedite customer billing. The primary target will be hard to access meter locations. Global Energy Metering Service estimates of the 150 million electric meters in the US, 17 million are hard to access. These meters typically cost 30 times the utilities average meter read cost. The system will also provide outage information, tamper detection, load control, profiling, and error detection.

5.4 FAISAT

FAISAT is a little LEO system that will provide global digital data communications. Final Analysis Inc. owns FAISAT. The system will provide asset monitoring and tracking, data acquisition, remote supervisory control, two-way data messaging, remote e-mail and file transfers, and alert monitoring. The system is scheduled to be operational by 2000.

5.4.1 Ground Segment

The three initial ground stations for the system will be located at Lanham, Maryland; Logan, Utah; and Andoya Rocket Range, Norway. Additional stations will be established as the commercial service operation is expanded. The Missions Operations Room in Lanham, Maryland will perform TT&C for the system.

5.4.2 Space Segment

The Space Segment will be composed of 38 operational and 6 in-orbit spare satellites. The constellation will be composed of seven orbital planes. One orbital plane with two satellites will have an inclination of 83°; the other six orbital planes, with six satellites each, will have inclinations of 65°. All satellites will be at an altitude of 1,000 km and will have a 5,000 km footprint.

The satellites will carry UHF/VHF multi-channel digital composite transceivers which use GMSK modulation and whip antennas. One experimental satellite was launched in 1995, and in 1997 Final Analysis launched a satellite with transponders for both FAISAT and VITAsat which are currently undergoing testing.

5.4.3 User Segment

Both fixed and mobile terminals will be supported. Mobile uplink frequencies are at VHF and UHF band. Mobile downlink frequencies are at VHF band. The uplink data rate is variable up to 19.2 kbps. The downlink data rate is variable up to 128 kbps.

5.4.4 Market

FAISAT will provide low cost global digital data services to support personal and business messaging, the transportation industry, scientific organizations, environmental organizations, the oil and gas industry, the agribusiness industry, the automotive industry, and the utility industry.

FAISAT also has a secondary payload program in which it will sell some of the space vehicles resources to support additional payloads for experimentation. It plans to market this program to Universities, Scientists, NASA and DoD Technology Programs, the Commercial Space Products Industry, and International Space Programs.

5.5 ICO

ICO, which is an independent company formed by Inmarsat, will be a MEO satellite system with global coverage. It will provide mobile voice, data, fax and messaging. The system will integrate mobile satellite communications with terrestrial networks. Launches are scheduled to begin in late 1998. The system should be partially operational by 2000.

5.5.1 Ground Segment

ICO will use a network of twelve earth stations or Satellite Access Nodes (SANs) to connect calls between the satellites and the PSTN. The U.S. earth station will be located in Brewster, WA. The earth stations are connected to each other through terrestrial high-speed links to form what ICO calls the ICONET. The ICONET earth stations will decide which satellite to use to route the call to the mobile customer. Each earth station will have multiple antennas so that it can communicate with more than one satellite at the same time. The ground stations will use uplinks and downlinks at C-band. Calls that originate from the mobile user will be routed via the satellites and the ICONET to the appropriate fixed or mobile network or another mobile satellite terminal.

One Satellite Control Center (SCC) will manage the ICO satellite system by handling tracking, telemetry and control. The SCC will also monitor the general conditions of the satellites. It will track the movements of the satellites and adjust their orbits to maintain the constellation. It will also dynamically reconfigure the channel allocation between high and low-traffic spot beams.

5.5.2 Space Segment

The ICO constellation will consist of ten MEO satellites at an altitude of 10,355 km. These satellites will be arranged in two orthogonal planes inclined at 45°. Each plane will consist of six satellites (one satellite in each plane is a spare). The satellite configuration is such that the entire surface of the earth is covered at all times and a mobile user will have more than one satellite in view usually at a high elevation angle (40–5°) at the same time. The satellites will have separate transmit and receive antennas for the mobile user. Each satellite will have 163 beams and be able to handle at least 4,500 simultaneous calls using TDMA (time division multiple access multiplexing). The satellites will be in direct contact with between two and four earth stations at the same time.

5.5.3 User Segment

ICO anticipates having several user terminals, one of which will be a hand-held mobile telephone. The hand-held unit would operate like a cellular phone when the user is outdoors. Both dual-mode and single terminals will be available. The dual-mode units will allow the user to select between cellular/PCS terrestrial systems and the satellite system. The service will offer digital voice at 4,800 bps and data at 38.4 kbps to mobile users. The mobile terminals will use both uplinks and downlinks at S-band.

5.5.4 Market

ICO's market is domestic and international travelers, business and government organizations, residents of rural and remote areas, vehicles, ships, and aircraft. ICO faces some regulatory hurdles in the United States, since the S-band that ICO will use is already occupied in the U.S. The FCC position is that ICO must pay to relocate the existing users of the spectrum. ICO with support from the European Union is contesting this ruling.

5.6 Leo One

Leo One is a data-only LEO satellite system owned by dBX Corporation. It will provide store-and-forward coverage of all points between the Arctic and Antarctic regions (between 65° South latitude and 65° North latitude using a 15° mask angle). DBX estimates that commercial service will be available beginning in 2000.

5.6.1 Ground Segment

The ground segment will consist of several earth stations configured as gateways. They will provide access to and from the terrestrial networks. The gateways will not be in continuous contact with the satellites due to the store and forward nature of the system. The gateways will periodically poll the satellites and assign a channel for down link. One of the gateways will handle tracking, telemetry and control of the constellation. The other gateways will act as back up TT&C. Another gateway will act as the network operations and control center (the other gateways will provide backup for this function also). It will handle store-and-forward management, optimum gateway relay station determination, user validation, and network performance monitoring.

5.6.2 Space Segment

The space segment will consist of 48 LEO satellites arranged in 8 orbital planes at an altitude of 950 km. The orbital planes will be equally spaced around the equator and inclined at an angle of 50°. The orbital period of the satellites will be approximately 104 minutes. The visibility to an earth station during each pass will be 7 to 10 minutes. The footprints of the satellites overlap ensuring a satellite is always visible to a user. Each satellite provides a circular coverage area with a diameter of 3,960 km assuming a minimum elevation angle of greater than 15° above the horizon. The satellite receives, demodulates and stores the data for each message. When the satellites are in range of the user or the earth stations, they encode, modulate, and retransmit the data.

5.6.3 User Segment

The transceivers will cost between $100 and $500. The units will be small, lightweight, and battery powered. The will be available in pocket sized, desktop and vehicle mounted configurations. The maximum transmit power will be 7 watts. The Leo One modem module is the heart of the system. Different modules will be added to the receiver depending on the purpose of the unit. The uplink and downlink frequencies are at VHF.

5.6.4 Market

The system will provide low-cost mobile and fixed service for industrial, business and personal data communications. The service cost will be competitive with terrestrial based systems. The service will provide vehicle tracking, status monitoring, emergency alerting, messaging, paging, positioning, data acquisition, and security monitoring.

5.7 SkyBridge

SkyBridge is a LEO satellite system that will provide broadband access to interactive multimedia services using two constellations of 32 satellites each. The system will provide worldwide coverage from 68° North latitude to 68° South latitude. It is intended to act as an extension of broadband terrestrial networks. The total capacity of the system is 144 Gbps. It will support between 15 and 20 million users. The service is expected to begin in 2001 with one constellation of 32 satellites.

5.7.1 Ground Segment

The ground segment is composed of the mission management system, which controls the overall system and 200 gateways. The earth stations or gateways connect the satellites with the terrestrial networks. They also handle the traffic routing, manage user access, billing, and are the service access point. Each gateway has a coverage area with a 350 km radius and has between one and four satellites visible at any given time. The gateways have up to 4 antennas for tracking satellites. They have the switching and routing system connecting with IP terrestrial networks, broadband and narrowband switched networks, and leased lines.

5.7.2 Space Segment

Each of the two constellations will consist of eight inclined planes with four satellites per plane. Each satellite will have a footprint of 3000 km. They will have a maximum of 45 steerable spotbeams each with a coverage area of 350 km per beam. Each satellite has a capacity of 4.7 Gbps. The capacity of one 350 km diameter spotbeam is 2.5 Gbps. There are no links between the satellites. Communications between the gateways and the satellites will be at Ku band.

5.7.3 User Segment

The user segment will consist of both residential and professional terminals. The residential terminal is composed of a small antenna with a radome that will mount on the roof of a building. It will provide service for one user with downlink data rate of 16 kbps to 60 Mbps and a uplink data rate of 16 kbps to 2 Mbps. The professional model will be larger and allow for higher data rates. SkyBridge predicts very low latency rates of 20 ms for 2-way propagation. User terminal uplinks and downlinks are both at Ku-band.

5.7.4 Market

SkyBridge is designed to complement terrestrial broadband networks. SkyBridge services will include Internet access, database interrogation, shopping, commercial transactions, banking, distance learning, telecommuting, email, teleconferencing, video on demand, & games. SkyBridge is primarily aimed at low or moderately populated areas (rural or suburban) where it is highly competitive to terrestrial links, and urban areas where terrestrial broadband networks are not yet available. SkyBridge expects to reach a market share of 15 to 20 million multimedia users.

6. On the Horizon (>2002)

There are numerous systems that have been proposed to start operation in 2002 and beyond. These are subdivided into two categories below; those proposing to use Ka-band and those proposing to use millimeter wave bands. Most of these systems (all of the millimeter wave band proposals) exist solely as FCC filings at this point. Because of this, there is little detailed information; what is known is discussed in the sections below. These systems however, are the future of satellite communications.

All of the systems fall into the category of broadband or multimedia data systems. They are designed to provide high speed data services, 1.544 Mbps to 155 Mbps and above, via satellite links. All of these systems are seeking to capitalize on the growing demand for high speed data services. The graph below, shows the projected global market for high speed data for the next decade.[21] As can be seen, all categories of high-speed data will increase dramatically over the next ten years. Many of the systems will compete directly with terrestrial infrastructure providers and submarine cables. These new broadband systems will also extend the benefits of satellite data services to a wider market. With projected prices of $1000 or less for terminals and access charges of $75–$100 per month, small business and consumers will be able to afford high speed network connections.

There are several important technological advances that make these new broadband systems possible. The advances are intersatellite links (ISL), onboard switching and processing, higher powered transponders, and narrow spot beams. Intersatellite links enable data to be routed from satellite to satellite using the shortest path length, reducing transmission time. The development of microwave switch matrices allows the full bandwidth of the transponder to be used with CDMA, TDMA, or FDMA techniques. Onboard baseband processing allows for mesh networks to be created with the satellites which allows single hop connections. The use of higher powered transponders coupled with narrow spot beams, provides higher power density to the mobile terminal, which allows for high data rates and small aperture antennas.

[21] Data from Satellite Data Networks: The Internet's Next Frontier, Pioneer Consulting, Cambridge MA, December 1997, pg. 94 and pg. 97.

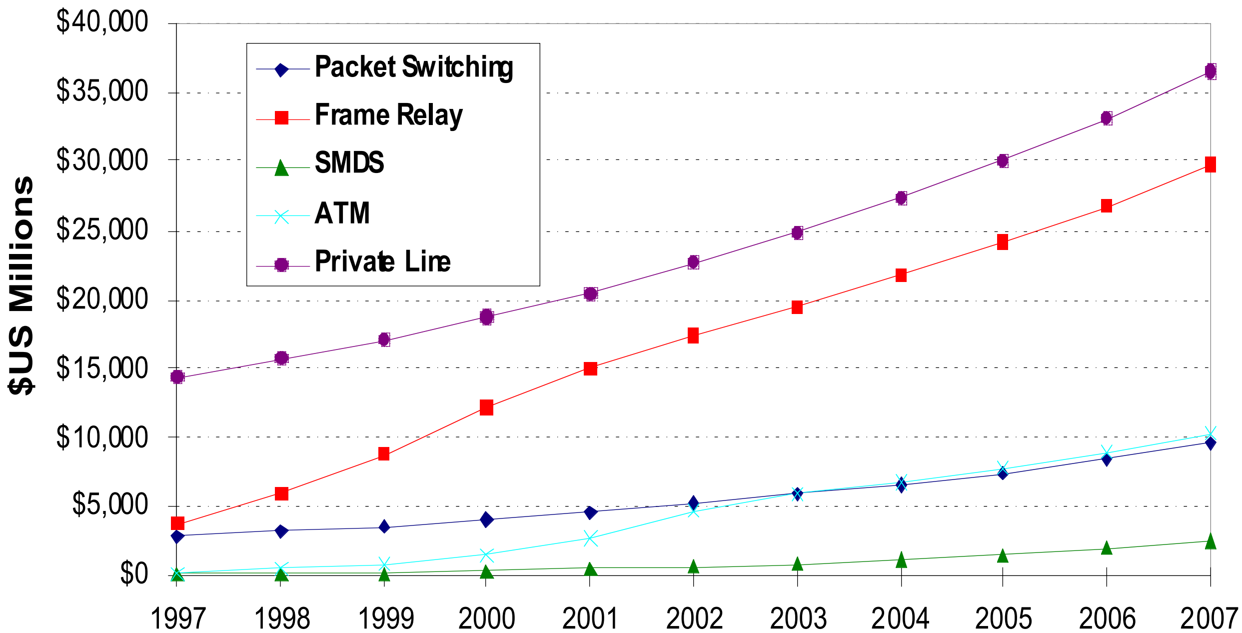

Figure 6-1 Global High Speed Data Market Forecast

6.1 Ka-Band

The Ka-band satellite market was made possible by NASA's Advanced Communications Technology Satellite (ACTS) Program. This experimental satellite was launched in 1993 to test the feasibility of satellite broadband services. The ACTS program allowed governmental organizations, industry, and universities to test out new concepts and technology. Some of the technology tested and demonstrated included high-gain hopping spot beams, on-orbit baseband and microwave switching, Ka-band high-bandwidth transponders, on-demand services, and ultra-small aperture services. Since rain-fade can be an issue at the Ka-band frequencies, compensation techniques were developed and tested. Many of these developments will be put into use in proposed commercial systems.

The first company to file for a FCC license for the Ka-band was Hughes Communications Inc., which filed an application for their Spaceway system in 1993. Since then they have modified their design, and delayed the introduction of their system several times. Teledesic Corporation followed with an application for a non-geostationary satellite orbit (NGSO) system in 1994. Since then numerous other companies have filed applications with the FCC. In March 1997, the FCC authorized Teledesic to construct, launch, and operate its NGSO system. Also in May 1997, the FCC authorized thirteen companies to construct, launch, and operate GSO systems. These Ka-band systems are summarized in Table 6-1 below. There are additional non-US systems that have been proposed and are in development, but they are outside the scope of this report.

All of these systems are considered broadband data systems. All of them except for VisionStar will provide two-way broadband data, VisionStar will provide interactive video. Many of these systems plan to market themselves as replacements for terrestrial T1/T3 links. All of the data systems will offer data rates in excess of 128 kbps. Most are T1 or E1 on the transmit side and

10+ Mbps on the receive side. All of these Ka-band systems except for Teledesic use geostationary satellites. Celestri is a hybrid system using both GEO and LEO satellites.

It is too soon to tell which of these systems will actually be launched; and of those launched, which will succeed economically. Already, one of the proposed systems, AT&T's VoiceSpan has been canceled. The other unknown at this point is which systems will support mobile users. So far, only Teledesic has made a commitment to support mobile users. Inmarsat Horizons with their maritime community background and Celestri with their LEO constellation probably will. A separate section is included on Teledesic since it is the only system at this time to be actively pursuing service to mobile users.

Table 6-1 Ka-band Systems

System	Prime Company(s)	System Type	# SATs	Data Rate (bps) xmt	rcv	Antenna Type/Size	Year Start Service	System Cost	Freq. Band
Astrolink	Lockheed Martin	GEO	9	2–155 M	2–155 M	0.2–1.8 m	2002	4 B	Ka
Celestri	Motorola	LEO/GEO	63/4	10 M	10 M	0.3–1.0 m	2003	12.9 B	Ka
CyberStar	Space Systems/Loral	GEO	3	384 k–3.088 M	92 M	0.9 m	1998 Ku / 2000 Ka	1.6 B	Ka/Ku
EchoStar	EchoStar Satellite Corp.	GEO	2	1.544 M	1.544 M	unknown	2002	unknown	Ka
GE*Star	GE Americom Communications Inc.	GEO	9	40 M	40 M	unknown	2002	4 B	Ka
Horizons	Inmarsat	GEO	4	144 k	144 k	A4 size	2002	unknown	S?
KaSTAR	KaSTAR Communications Corp.	GEO	2	unknown	unknown	unknown	2002	645 M	Ka
Morning Star	Morning Star Satellite Co. LLC	GEO	4	64 k	30 M	unknown	2002	936 M	Ka
NetSat 28	NetSat 28	GEO	1	1.544 M	1.544 M	1 m	2002	250 M	Ka
Orion Network Systems	Orion Network Systems, Inc.	GEO	3	1.544 M	90 M	1.2 m	2002	500 M	Ka
PAS 10 / PAS 11	PanAmSat Licensee Corp.	GEO	2	56 k– 45 M	56 k– 45 M	unknown	2002	409 M	Ka
Spaceway	Hughes Communications Galaxy Inc.	GEO	21	384 k– 6 M	108 M	0.66 m–3.5 m	2002	5.1 B	Ka/Ku
Teledesic	Teledesic Corp.	LEO	288	16 k–2 M	64 M	0.16–1.8 m	2002	9 B	Ka
VisionStar	VisionStar, Inc.	GEO	1	limited	100 video ch	unknown	2002	207.5	Ka
VoiceSpan	AT&T	GEO	12	1.544 M	1.544 M	0.67 m	canceled	N/A	Ka

6.1.1 Teledesic

Teledesic will be a Ka-band LEO satellite system consisting of 288 satellites in a 1,350 km orbit. The system will provide high capacity broadband data and voice services with low latency to extend networks to most places on earth. The goal of the system is to have the same characteristics as a terrestrial fiber network. This differs from the service other LEO systems will offer which are more similar to cellular phone service. The coverage area is expected to be 95% of the earth's land mass and 100% of populated areas. Teledesic was formed in 1990. The FCC granted Teledesic a license in March 1997. The first launch is anticipated in 2000 and service is expected to start in 2002. Teledesic is a privately held company owned by Bill Gates, Craig McCaw and Boeing.

6.1.1.1 Ground Segment

Details of the Teledesic ground segment are not known at this time.

6.1.1.2 Space Segment

The Space Segment consists of 288 operational satellites in 12 planes with a polar orbit. Each plane will have 24 satellites. Each satellite is a node in the fast packet switched network that has communications with satellites in the same or adjacent orbital planes. This arrangement is more tolerant of faults and local congestion. Each spot beam has a foot print with a radius of 100 km. The small foot print allows for bandwidth reuse. Teledesic essentially has 500 MHz of down link and 500 MHz of uplink bandwidth for every 31,416 square kilometers. The constellation configuration is such that the user will have a view of a satellite with a minimum 40º elevation. The uplink will operate between 28.6 and 29.1 GHz. and use Multi-Frequency Time Division Multiplexing (MF-TDMA). The down link will operate between 18.8 and 19.3 GHz and use Asynchronous Time Division Multiplexing Access (ATDMA).

6.1.1.3 User Segment

The system will provide service for fixed and mobile users. Most user terminals will have up to 64 Mbps downlink and 2 Mbps uplink. Broadband terminals will also be available. The broadband terminals will provide 64 Mbps in both directions. The antennas will be about the size of direct broadcast satellite (DBS) dishes. The system will be designed to support bandwidth on demand for the user. The user will pay only for the capacity they actually use.

6.1.1.4 Market

The system will provide broadband digital access at an affordable cost to information workers anywhere in the world from fixed terminals. Internet/Intranet accesses are likely to be key markets. The systems goal is to act as an Internet in the sky with fiber quality. Teledesic does not intend to market its' service directly to users, but through other service providers.

6.2 Millimeter Wave

The term "millimeter wave" refers to the portion of the spectrum band in the high EHF range where the wavelengths are measured in millimeters. This includes the Q, V, and W bands. Prior to 1994 the research into millimeter wave technology was primarily funded by the government for military purposes. However, the desire for more bandwidth led commercial companies to start looking at these frequencies. In 1994, the FCC initiated a rulemaking proceeding to open up 18 GHz of spectrum in the millimeter wave band for commercial use. In early 1997, the FCC announced a preliminary plan to designate 4 GHz of spectrum in the Q and V bands as primary for FSS.

Fifteen companies quickly filed applications for systems to use this spectrum. However, these systems are the most speculative of any of the proposed new systems. Most of these systems plan to use new and untested digital and space technology. Much of the equipment to operate at these frequency bands has not been built or tested. In addition, there are economic uncertainties associated with these systems. Although difficult to predict which system(s) will end up being built and which will be economically viable, it is certain that not all of those proposed will survive. In fact, one of the systems has already been withdrawn: Motorola's M-Star has been folded into their Celestri proposal.

Since these systems exist only as proposals at this time, getting detailed information is difficult. Some characteristics of twelve of the systems are summarized in Table 6-2 below. Many of these systems are looking at competing with terrestrial T1/T3 and fiber links. Some of these systems will support only fixed sites; which ones will support mobile terminals is not known at this time. Only Hughes' StarLynx system has specifically targeted mobile terminals.

Table 6-2 Millimeter Wave Systems

System	Prime Company(s)	System Type	# SATs	Data Rate (bps) xmt	Data Rate (bps) rcv	Year Start Service	System Cost	Freq. Band
Aster	Spectrum Astro, Inc.	GEO	25	2–622 M	2–622 M	2002?	2.357 B	V
CyberPath	Loral Space & Communications, Ltd.	GEO	10	3.088–6 M	3.088–89.6 M	2002	1.174 B	V
Expressway	Hughes Communications Inc.	GEO	14	1.544–155 M	1.544–155 M	2004	3.925 B	V/Ku
GE*Star Plus	GE American Communications, Inc.	GEO	11	155 M	155 M	2002?	3.37 B	V/Ku
GESN	TRW, Inc.	MEO/GEO	15/4	1.5 M–3 G	1.5 M–3 G	2003?	3.4 B	V
Globalstar GS-40	Globalstar L.P.	LEO	80	2.048–51.84 M	2.048–51.84 M	2002?	unknown	V
OrbLink	Orbital Sciences Corp.	MEO	7	1.5 M–1.25 G	1.5 M–1.25 G	2002	900 M	V
Pentriad	Denali Telecom, LLC	MEO/HEO	9	10 M–3.875G	10 M–3.875G	2002?	1.89 B	Q/V
Q/V-band	Lockheed Martin Corp.	GEO	9	384 k–9.2 M	384 k–9.2 M	2004?	4.75 B	V
SpaceCast	Hughes Communications Inc.	GEO	6	155 M	155 M	2004?	2 B	V/Ku
StarLynx	Hughes Communications Inc.	MEO/GEO	20/4	4 k–8 M	4 k–8 M	2004?	2.871 B	V
V-Stream	PanAmSat Corp.	GEO	12	1.544–155 M	1.544–155 M	2005?	3.5 B	V

7. Satellite Systems Test and Evaluation

One of the objectives of the Mobile Communications Infrastructure project is to conduct in-depth evaluations of mobile satellite systems that appear to meet Coast Guard communications requirements. The goal in testing these systems is to quantify how well they work and to provide some metrics to see how each of these systems could fit the needs of the Coast Guard. There are a variety of parameters we will measure for each system. Most of the measurements will be of the overall system, not the individual pieces. The measures will include: coverage, availability, reliability, accuracy, interoperability, bandwidth, latency, ease of use, cost, and security features. Some testing will be performed in the Advanced Communications Lab at the R&D Center, and some will be performed by placing systems on operational units for field tests.

7.1 Measurement Parameters

7.1.1 Coverage

Coverage is the geographic area in which a mobile user has access to the satellite system. The vendor typically provides a coverage diagram of the service area. This could be a map or chart showing the geographic area in which the system operates. This area is composed of the "footprint(s)" of the satellite or satellites that make up the system.. Prediction of coverage area will be calculated using Satellite ToolKit (STK) software. In addition, coverage of some systems will be verified by field tests.

7.1.2 Availability

Availability is the amount of unit time on any given day that the system is available for use. Reasons for non-availability could include: the traffic exceeds the capacity of the system, the system is temporarily out of service, a satellite is not in view. Failure of user equipment would not be a reason for system non-availability. Prediction of the number of satellites in view and system availability will be calculated using Satellite ToolKit software. This will also be checked by lab and field tests.

7.1.3 Reliability

Reliability is a measure of a system's dependability. This will be evaluated in the lab and the field by monitoring and recording equipment failures.

7.1.4 Accuracy

Accuracy is a measure of the absence of error. Examples of accuracy in a voice or data system would be: Can you understand what the person is saying? Do you recognize his/her voice? Is the data sent on one end of the system the same as the data received at the other end? What is the Bit Error Rate? This will be measured by testing conducted in the lab.

7.1.5 Interoperability

Interoperability is a measure of how well the system interfaces or integrates with existing systems. For example: Is it a circuit switched system that works with the Public Switched Telephone system. This would mean it might work like a telephone, fax, or modem. Does it work like a packet switched system? How would we integrate it with existing Coast Guard systems? How would we use it? This will be determined by lab testing.

7.1.6 Bandwidth

Bandwidth is the width of the communications channel and is a measure of how much information can be transferred by the channel. For analog voice this would be in cycles per second, for data or digital voice this would be in bits per second. This is typically stated by the system manufacturer. It will be verified by lab testing.

7.1.7 Latency

Latency is the end-to-end delay in the system. In a data transmission, this metric can be just as important as speed or bandwidth of the channel. It is affected by a variety of things. The first and most obvious would be the length of the path. Other parts of the delay would be due to other factors i.e., the earth station, buffering, system loading, and congestion. This will be measured in lab testing.

7.1.8 Ease of Use

How easy is the system to use? Is it like using a standard phone, fax or modem? This will be evaluated by lab and field tests.

7.1.9 Cost

Here we will look at the costs associated with each system. These would include equipment costs and recurring service fees. Equipment costs would be life cycle costs such as: initial acquisition, installation, training and maintenance. They tend vary for each mobile platform. Recurring service fees would be the monthly access fees, and a usage fee based on airtime or the amount of data sent. This data will be compiled based upon inputs from the system and service providers.

7.1.10 Security

Security involves how the system will protect the privacy and integrity of user data. This is typically done through some type of encryption scheme. This information will be obtained from the system manufacturer. Each system will be evaluated on whether security is provided, and if so, how, and to what level of classification.

7.2 System Test Plans

The following tables contain the test plans as they exist now. As system capabilities and start dates change, the plans will be modified as necessary.

Table 7-1 Systems That Will Not Be Tested

SYSTEM	Reason Not Tested	Capabilities
Inmarsat A,C	Both of these systems are in use on USCG Vessels already	Inmarsat-A: analog voice, 9,600–14,400 bps data, high speed data option (56 kbps), compressed video, fax. Inmarsat-C: data only, store and forward, text or data, 600 bps.
Inmarsat D	Not suitable for USCG use	Paging system with acknowledgment function.
Argos	Not suitable for USCG use	Environmental data collection, low speed data, store and forward.
VITAsat	Not suitable for USCG use	Provides services in developing countries. Data-only system.
FAISAT	Similar to ORBCOMM	Provides tracking, e-mail, paging (2-way short digital & alphanumeric messages), monitoring, location determination, and distress signaling.

Table 7-2 Systems That Have Already Been Tested

System	Testing Status	Capabilities
QUALCOMM (BOATRACS)	USCG currently testing this system in D8. Results will be reported separately.	Provides Tracking and 2-way short digital messaging with acknowledgment.
AMSC	USCG tested this system during the Operational Information System Phase 2 (OIS2) and Operational Web Link (OWL) projects. Additional testing done in lab. Informational report to follow.	Voice, fax, 4800 bps data, digital messaging, packet data.

Table 7-3 Systems To Be Tested This Year

System	Testing Status	Capabilities
Inmarsat Mini-M	Lab testing during March - April 1998. Some units currently installed on D14 WPBs as a CG prototype.	Digitized voice, fax, 2400 bps data, messaging.
DirecPC	Lab testing during March - April 1998.	High speed data (400 kbps), receive only. Needs separate return link. Investigated shipboard use in 1997 but the signal strength from the current transponder is too weak offshore.
GBS	Shipboard testing 1998.	Provides broadband broadcast channel (receive only). DoD developed system.
Iridium	Lab and Shipboard testing summer 1998	Digitized voice, 2400 bps data, fax, and paging.
ORBCOMM	Lab and Shipboard testing summer 1998.	Data-only system, 2400 bps data, messaging, and positioning.

Table 7-4 Systems To Be Tested Next Year

System	Testing Status	Capabilities
CyberStar	Will schedule testing as system comes online.	Initially, Ku-band, switching to Ka in 2000. Broadband data.
Globalstar	Both Lab and shipboard testing, early 1999.	Digitized voice, fax, 9600 bps data, and positioning.
Turbosat	Will schedule testing as system comes online.	Broadband data.

8. Conclusions

Currently there are only five satellite systems with a total of 10 satellites in operation (counting only those systems that support communications to mobile users). Over the next ten years, 41 proposed systems totaling over 1,000 satellites will be launched into GEO, MEO, and LEO orbits. While not all of these systems will actually be launched and successful, there will still be an incredible number of options to choose from. Unfortunately, for many of these proposed systems, it is not known to what extent they will support mobile terminals.

This technology assessment contains the most accurate data that could be currently obtained. However, as systems are launched and tested, system parameters tend to change as solutions to technical problems are engineered to follow changing markets. The services finally offered to the public could be different than those stated in this report. The industry will need to be tracked over the next several years, as some systems are launched and plans are solidified on others. The Mobile Communications Infrastructure project will accomplish this. The project plan calls for this Satellite Alternatives technology assessment to be revisited and updated in the first quarter of FY00.

As systems are actually launched, those that appear likely to meet Coast Guard communications requirements will be tested, both in the lab and in the field. The testing will be conducted in order to verify stated performance and to evaluate how well the system meets Coast Guard requirements. Both Coast Guard Command and Control (C^2) and Distress and Safety requirements will be addressed. Distress and Safety requirements will include Coast Guard Distress and Safety communications as well as civilian GMDSS-type requirements. In addition, how the system meets Enhanced-911 reporting requirements will also be evaluated. A preliminary report will be completed on each system tested and evaluated. Currently, the Inmarsat Mini-M system is being tested. Iridium and ORBCOMM will be tested this spring/summer, and Globalstar will be tested as soon as it is available. CyberStar and Turbosat will tested if they appear able to meet Coast Guard requirements. The individual test reports will be all consolidated into a MSAT Evaluation Report in the Second Quarter of FY99. Finally, as cost data becomes available, cost benefit analyses comparing the different systems, will be done in order to identify which systems the Coast Guard should procure.

It is doubtful that a one-size-fits-all type solution exists. Due to the wide variance in Coast Guard missions and platforms, it is more likely that different systems will be best for different platforms. There are three categories of service: data-only, voice/data, and broadband data. Currently, shipboard systems are only available in the first two categories. A shipboard terminal for two-way broadband data will probably not be available until the Ka-band systems are operational in 2002.

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ACRONYMS

AMPS	Advanced Mobile Phone Service (U.S. Analog Cellular)
ATDMA	Asynchronous Time Division Multiple Access
bps	bits per second
CDMA	Code Division Multiple Access
CES	Coast Earth Station
CONUS	CONtinental United States
COTS	Commercial Off-The-Shelf
DAMA	Demand-Assigned Multiple Access
DBS	Direct Broadcast Satellite
DoD	Department of Defense
FCC	Federal Communications Commission
FDMA	Frequency Division Multiple Access
FEC	Forward Error Correction
FSS	Fixed Satellite Service
Gbps	Giga bits per second (1,000,000,000 bps)
GBS	Global Broadcast System
GCS	Ground Control Stations
GDN	Globalstar Data Network
GEO	GEostationary Orbit
GES	Gateway Earth Station
GES	Ground Earth Stations
GHz	Giga Hertz (1,000,000,000 Hz)
GMDSS	Global Maritime Distress and Safety System
GMSK	Gaussian Minimum Shift Keying
GOCC	Ground Operations Control Center
GPC	Global Processing Center
GPS	Global Positioning System
GSM	Global System for Mobile communications
GSO	Geostationary Satellite Orbit
HEO	Highly Elliptical Orbit
HF	High Frequency
Hz	Hertz
ICO	Intermediate Circular Orbit
Inmarsat	International Maritime Satellite Organization
Intelsat	International Telecommunications Satellite Organization
IS-41	Standard AMPS Cellular
IS-95	Standard for CDMA Digital Cellular (US)
ISP	Internet Service Provider
ITU	International Telecommunications Union
kbps	kilo bits per second (1,000 bps)

kg	kilogram (1,000 g)
kHz	kilo Hertz (1,000 Hz)
km	kilometers (1,000 m)
LEIS II	Law Enforcement Information System II
LEO	Low Earth Orbit
LES	Land Earth Stations
m	meters
Mbps	Mega bits per second (1,000,000 bps)
MCT	Mobile Communications Terminal
MEO	Medium Earth Orbit
MES	Mobile Earth Station
MF-TDMA	Multi-Frequency Time Division Multiple Access
MHz	Mega Hertz (1,000,000 Hz)
MILSATCOM	MILitary SATellite COMmunications
MOU	Memorandum Of Understanding
ms	milliseconds
MSAT	Mobile SATellite
MSS	Mobile Satellite Services
NASA	National Aeronautics and Space Administration
NCC	Network Control Center
NCS	Network Control Station
NGSO	Non-Geostationary Satellite Orbit
NOAA	National Oceanic and Atmospheric Administration
NOC	Network Operations Center
PC	Personal Computer
PLMN	Public Land Mobile Network
POES	Polar Orbiting Environmental Satellites
PPP	Point-to-Point Protocol
PSDN	Public Switched Data Network
PSTN	Public Switched Telephone Network
PTT	Platform Transmitter Terminals
R&D	Research and Development
RF	Radio Frequency
RMA	Random Multiple Access
RNCC	Regional Network Control Center
RPC	Regional Processing Center
SC	Subscriber Communicator
SCADA	Supervisory, Control, And Data Acquisition
SCPC	Single Channel Per Carrier
SDMA	Space Division Multiple Access
SMF	Satellite Maintenance Facility
SOCC	Satellite Operations Control Center
SOHO	Small Office / Home Office
SS7	Signaling System 7
TCP/IP	Transmission Control Protocol / Internet Protocol
TDM	Time Division Multiplexing
TDMA	Time Division Multiple Access

TT&C	Telemetry, Tracking, and Control
UHF	Ultra High Frequency
UFO	UHF Follow On
USCG	United States Coast Guard
VHF	Very High Frequency
WRC	World Radio Conference

Appendices*

*** Appendices have been published as a separate Addendum available from the Research and Development Center upon request.**

A. Summary Information of Satellite Systems Separated into the Following Tables:

1. General Information
2. Ground Segment
3. Space Segment
4. User Segment
5. User Terminal

B. Complete Information on the Satellite Systems